674-EPO-100, v2.1

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Space Infrared Telescope Facility

Education and Public Outreach (EPO) Plan

1998 May 18, Version 2.1

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL D-15476

674-EPO-100, v2.1

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Space Infrared Telescope Facility

Education and Public Outreach (EPO) Plan

Approved By

Responsible For

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1998 May 18, Version 2.1

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Space Infrared Telescope Facility

Education and Public Outreach (EPO) Plan

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Space Infrared Telescope Facility

Education and Public Outreach (EPO) Plan

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{ Signed 1998 April 28 }

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NASA Office of Space Science Vision for Education and Public Outreach:

"The Office of Space Science will use its knowledge and discoveries about the Sun, the Solar System, the Galaxy, and the Universe to develop Education and Public Outreach opportunities and activities that enhance science, mathematics, and technology education and the scientific and technical literacy of all Americans."

NASA Office of Space Science Mission for Education and Public Outreach:

"The education mission of the Office of Space Science is to engage its community of research scientists, managers, engineers, and support staff across the nation in Education and Public Outreach activities to fulfill its vision. To this end, OSS will use all its resources, specifically drawing on the inspirational nature of space science; the remarkable results from its missions; and the special talents of its research community in universities, institutes, and laboratories throughout the country."

Executive Summary

The *Space InfraRed Telescope Facility* (SIRTF) presents its Education and Public Outreach (EPO) Plan. The Plan establishes the contextual framework in which SIRTF's EPO programs will be developed and implemented, and is intended to complement the activities described in the companion SIRTF Public Affairs Plan (to be submitted separately by the JPL Public Affairs Office). This Plan identifies three keys that SIRTF will exploit in the development of its EPO program: (i) SIRTF's role as the fourth and final element of NASA's "Great Observatories" program; (ii) the role of technology development in enabling scientific discoveries, particularly in infrared astronomy; and (iii) the role of discovery in science, and the ways in which our understanding of the cosmos evolves.

The vision of SIRTF's EPO program is to *focus on areas where SIRTF can make a powerful, and often a unique, contribution to NASA's EPO program in space science, and to seek maximum leveraging opportunities with complementary NASA/OSS missions and programs, and with external groups that have already developed space science educational materials*

This Plan defines the primary themes for which specific EPO modules will be designed, developed, tested, and implemented. These themes, and the detailed products and modules to be developed, are aligned with national education standards for science, mathematics, and technology. The themes follow naturally from the scientific capabilities provided by SIRTF, from the expertise inherent in the EPO staff, from suggestions offered by members of the education community, and from recognition of what already exists in the rapidly expanding universe of space science education.

The first theme that will be developed by SIRTF is the concept of temperature, and its relation to the electromagnetic spectrum. The second will consider the fact that virtually all astronomy knowledge is obtained remotely, and examine how photons are transformed into knowledge. It will also explore how astronomers visualize, portray, and interpret data. The SIRTF team will also focus on a third theme, and offer insight into the scientific process itself. We will develop an inquiry-based set of modules that illuminate the underlying processes in which scientists frame the Big Questions, define methods suitable for seeking the answers to those questions, construct the tools needed to permit measurements to be conducted, and examine how theory and observation interplay in the evolution of knowledge. SIRTF will carefully study the possibility of permitting groups of students, teachers and the general public to actively participate in the planning and execution of some observations aboard SIRTF, and to analyze and interpret the data afterwards.

The SIRTF science program suggests that its education and public outreach program be integrated into the content and infrastructure of NASA's Origins, SEU, and SolSysEx EPO Forums, and with the goals inherent in NASA Education's Strategic Plan. SIRTF will collaborate with the EPO programs of other related space science programs, and jointly develop material highlighting the synergistic relationship between SIRTF and programs such as HST, SOFIA, WIRE, and 2MASS. The EPO Plan also includes descriptions of how the Internet/WWW will be utilized for both outreach and scientific purposes, and concludes with its description of how it intends to evaluate the quality, impact, and effectiveness of the proposed education and public outreach programs.

1. Introduction

After a quarter century of dreams and designs, the *Space InfraRed Telescope Facility* (SIRTF) begins formal development in 1998, with launch scheduled for December 2001. SIRTF represents the final element in NASA's suite of "Great Observatories," and a scientific and technical bridge to NASA's ambitious new *Origins* program. Congressional approval of SIRTF in the past year provides an emphatic exclamation mark to NASA's completion of the space-based initiatives recommended in the National Academy of Science's review of decadal priorities for astronomy and astrophysics in the 1990s (the "Bahcall Report"). SIRTF's technical capabilities, in combination with the compelling scientific basis for studying the Universe at infrared wavelengths, virtually assures that its legacy will favorably compare with those of the *Hubble Space Telescope,* the *Compton Gamma-Ray Observatory*, and the imminent results from the *Advanced X-Ray Astrophysics Facility*. The "Decade of the Infrared" has also become the decade in which NASA has properly recognized the unmatched human interest in space science, and the degree to which the amazing discoveries, being made almost routinely, enthrall the American public.

This document describes the SIRTF Education and Public Outreach (EPO) Plan. The EPO activities for SIRTF will be coordinated and managed by the SIRTF Science Center (SSC), based at the Infrared Processing and Analysis Center (IPAC) on the campus of the California Institute of Technology in Pasadena. The efforts will also be augmented with editorial contributions and oversight from the SIRTF Project Office at the Jet Propulsion Laboratory (JPL), by members of the SIRTF Science Working Group (SWG) and by the appropriate SSC/IPAC advisory committees. It is anticipated that a significant amount of the actual manufacture of products and the implementation of plans will involve resources external to JPL and Caltech, especially members of the formal and informal (e.g., museums and planetariums) education communities.

This EPO Plan describes the vision and the themes where SIRTF offers the potential for making its greatest impact in the areas of education and public outreach. These themes follow naturally from the scientific capabilities provided by SIRTF, from the expertise inherent in the SSC staff, from suggestions offered by members of the education community, and from recognition of what already exists in the rapidly expanding universe of space science education. While some specific education concepts and modules will be presented in this Plan, many of the detailed implementation schemes will be defined over the next year, following the formal start of the Project's development phase.

As a "Great Observatory," SIRTF recognizes that its EPO efforts must be multi-faceted, and directed towards all segments of the K-13 community, and to both the formal and informal educational communities.

The vision for SIRTF's EPO activities is to *focus on areas where SIRTF can make a powerful, and often a unique, contribution to NASA's EPO program in space science, and to seek maximum leveraging opportunities with complementary NASA/OSS missions and programs, and with external groups that have already developed space science educational materials.* The SIRTF activities will be a mix of scientific, technical, and human-interest topics, some of which are presented in Section 3.

The SIRTF EPO program will be designed to accommodate the strategies described in the March 1995 document, "*Partners in Education: A Strategy for Integrating Education and Public Outreach into NASA's Space Science Programs."* This is taken to be the "constitutional" framework for establishing the Basic Policies for integrating EPO throughout all NASA/OSS activities. This document comprises one volume of the NASA Strategic Plan published in 1994 (since updated), and represents a component of NASA's overall contribution to a national initiative to dramatically improve education and scientific and technical literacy in the US (the primary NASA/OSS EPO strategies are listed in Appendix A). The SIRTF EPO plans are also intended to be consistent with the implementation principles described in the companion October 1996 report, "*Implementing the Office of Space Science (OSS) Education/Public Outreach Strategy*." This document summarizes the results from a study by the OSS-Space Science Advisory Committee (SScAC) Education/Public Outreach Task Force, and lays out the actions required to put the Basic Policies into practice. The major NASA/OSS principles of EPO implementation are listed in Appendix B of this Plan.

The EPO products to be developed in the implementation of this Plan will be aligned with the national education standards for science, mathematics, and technology. The relevant portions of these standards are presented in Tables 1-3. SIRTF’s EPO efforts will exploit the unique attributes of the SIRTF mission and the compelling science that motivates the program, while ensuring congruence with national education standards.

The SIRTF EPO program is budgeted at an aggregate $3 million during the Project’s development phase (0.7 percent of the Phase C/D cost), and at about $1.3 million annually during the mission's post-launch operations phase -- a total of about $9.5 million over the next 9.5 years (see Appendix F for annual EPO budgets). The implementation document referenced above states that the long-term goal of NASA/OSS is to allocate 1-2 percent of its total OSS budget for EPO. These funds are intended to support not only the mission-specific EPO efforts, but also those associated with the components of the integrated network of national resources (including the EPO Forums and Brokers/Facilitators to be discussed in Section 4) and the *Initiative to Develop Education through Astronomy* (IDEA) grants program.

SIRTF has twice been redesigned and rescoped and its programmatic approval has come in the midst of a major transition in NASA/OSS, in both the organizational structure and in its newly codified interest in education and public outreach. Nevertheless, as a "Great Observatory," SIRTF recognizes its significance in the OSS Space Science Enterprise over the next decade, along with the EPO opportunities and expectations that follow. It is noted that the entire SIRTF EPO budget represents 2.1 percent of the mission's development cost, and 1.2 percent of the anticipated lifecycle costs.

SIRTF's activities in the areas of education and public outreach will be managed from the SSC, under the direction of Dr. Michael D. Bicay, Manager of IPAC Education and Public Outreach and of SIRTF Science Outreach. External guidance and editorial development will continue to be provided by Dr. Marcia J. Rieke (Steward Observatory, University of Arizona), Outreach Coordinator on the SIRTF Science Working Group. SIRTF/IPAC EPO will also be organizing an external advisory committee of scientists, science educators, and teachers to provide ongoing advice pertaining to all elements of IPAC and SIRTF EPO. The EPO office has recently been established at the SSC/IPAC, coincident with the start of the Project’s Phase C/D in April 1998. The primary goal of pre-launch EPO activities will be to establish a proper context for the public appreciation and understanding of the SIRTF data once they become available in early 2002.

2. Keys to SIRTF's Approach

Before describing SIRTF's EPO plan, it is useful to briefly consider the keys that make SIRTF well-positioned, perhaps uniquely so, in pursuing some of the themes to be introduced in Section 3. These keys establish a framework for public awareness of SIRTF's features and its capabilities, placing the mission into a comfortable context from which more detailed themes can be developed.

The SIRTF EPO efforts will focus on developing material that either complements the existing body of "literature" and products, or fills important niches for which content is sparse or non-existent, and for which SIRTF can logically and naturally provide valuable content. Some of the themes presented in Section 3 are obvious, given the scientific motivation for SIRTF. Others emerged from discussions between members of the SIRTF team, representatives of the NASA education community, and from teachers attending scientific meetings.

2.1 Final Element of the "Great Observatories"

SIRTF is the infrared tool in NASA's panchromatic armada of "Great Observatories," designed to provide multi-wavelength and contemporaneous observational capabilities over large regions of the electromagnetic (EM) spectrum. The programmatic (mis)adventures of the *Hubble Space Telescope*, the heroic compensatory fixes, the ongoing Shuttle servicing missions, and the steady stream of widely disseminated scientific discoveries have firmly planted HST and the concept of NASA's Great Observatories into the collective conscience of not only scientists, but the public at-large. This intense interest is likely to be amplified within a year by the launch and Shuttle deployment of the *Advanced X-Ray Astrophysics Facility*, and by the 1999 and 2002 Shuttle servicing missions to HST.

Portraying SIRTF as the "infrared version of the HST" establishes a contextual reference in the broad community, while permitting an obvious launching point for describing the wealth of information that is obtainable only in the infrared portion of the EM spectrum. Moreover, it naturally suggests development of a primer on why NASA needs to send many of these observatories into space.

Much material is already available in the literature (online, and otherwise) on the subjects of "light" and the EM spectrum. A lesser amount is devoted to the concepts of atmospheric transmission and opacity, and the reasons for deploying ground- and space-based and airborne observatories. Rather than limit development efforts to the standard treatment of electromagnetic radiation, the SIRTF team will develop material focusing on the concepts of thermal physics, or temperature (see Section 3.3 for details).

2.2 Technology Enables Science

A common attribute of many NASA space science missions is the extent to which technology developments play a major role in enabling the necessary advances in design and development for making today's fascinating discoveries. It is remarkable to consider that well into the 20th century, the only astronomy practiced was through the sliver of the EM spectrum for which the human eye is sensitive -- optical astronomy. (While one might argue that the birth of optical astronomy coincided with the invention of the telescope by Galileo in 1609, it is equally persuasive to argue that optical astronomy has been practiced since humans crawled out of caves.)

The birth of radio astronomy in the 1930s was followed by a dramatic revolution in receiver technology, primarily as a result of the military applications developed during World War II. The dawning of X-ray astronomy came via sounding rockets in the late 1950s, and was followed by orbiting satellites in the 1970s. Infrared astronomy had been limited to studies within a handful of narrow atmospheric bands in the 1960s and 1970s, primarily from dry mountain sites and from aircraft. The incredibly rich potential of IR astronomy was fully revealed by the first space-based infrared telescope, the *Infrared Astronomical Satellite (IRAS)*, an Explorer mission that surveyed most of the sky during its 10-month lifetime in 1983. In each of these new fields of astronomy, the secrets of the cosmos could only begin to be revealed once the proper telescope and detector technologies had achieved maturity.

The coupling between engineering and science is particularly evident in the field of infrared astronomy. In a situation analogous to radio astronomy half a century ago, infrared astronomy has benefited immensely from the military development of IR sensors. Astronomy applications require detector and electronics improvements for use in low-background applications, and normally require the refrigeration of telescopes and science instruments to within a few degrees of absolute zero. With these tools now in hand, astronomers are able to fully explore the rich body of science uniquely revealed in the infrared, from the studies of star formation to the formation of primeval galaxies in the early Universe.

The political ramifications of an increased concern about expanding federal budget deficits by the US electorate in the early 1990s forced the original $2.2 billion version of SIRTF (as measured by development costs) to be rescoped twice to its current $0.45 billion cost. But as an illustrative example of the impact that ingenious engineering can have on scientific capability, one would be hard pressed to find an example whose benefits will exceed those from SIRTF. Despite the ~80% cost reduction, clever engineering has preserved much of SIRTF's science potential. Some examples of "better science through engineering" will be described in Section 3.5.2.

2.3 The Role of Discovery in Science

Given a telescope of meter-class aperture, cooled background-limited detectors, and a benign thermal orbit, SIRTF immensely extends astronomer's capabilities in the infrared over previous observatories. For example, SIRTF's sensitivity will exceed that of the premier IR observatory of the 1990s, the *Infrared Space Observatory (ISO)*, by a factor of ten at the longer wavelengths, and by factors of hundreds in the near-infrared. However, a more comprehensive measure of this next-generation capability accounts for SIRTF's predicted observing efficiency, its longer lifetime, and the large-format IR detector arrays onboard. Taken together, SIRTF offers the potential of being many orders of magnitude more capable than any past or present infrared observatory. In an era where NASA space science is in transition to smaller missions with increasingly focused scientific goals, SIRTF may represent the last broad-based "orders of magnitude" advance in observational capabilities, for at least the near future.

SIRTF is not only likely to expand our knowledge of celestial objects initially discovered by IRAS and studied by ISO, but is almost certain to make entirely new discoveries. While the mission lifetime requirement remains a modest 2.5 years, the engineering approaches to be introduced in Section 3.5.2 make it increasingly likely that SIRTF will achieve a cryogenic mission lifetime of five years. This is critically important, because the usual cycle of

Plan→Propose→Observe→Analyze→Interpret→Publish→Plan→Re-propose

often takes a couple of years to unfold. SIRTF will be an ideal tool, and in some cases the only tool, to conduct follow-up investigations of its own discoveries. The scientific process by which knowledge evolves is an attractive concept for a SIRTF EPO module that goes beyond the "final results" that often are presented in the news media and textbooks. A revealing look at the "how" of science is likely to lead to a far greater appreciation of the scientific endeavor by the broader community, particularly young people. It behooves us to offer the public an opportunity to look "behind the scenes" at how the pursuit of science is conducted and to establish a human connectivity to the great discoveries (see Section 3.5).

3. SIRTF's EPO Themes

In this section, we introduce some of the conceptual themes that SIRTF EPO intends to pursue. These themes will serve as the intellectual motivation and starting points for the detailed definition, development, implementation and evaluation of EPO modules (to be defined in the next subsection). With the SIRTF Project having just entered its formal development phase, it is now anticipated that SIRTF EPO will devote a significant fraction of the next year to creating a detailed implementation plan of activities, products and services to be developed during the next nine years. (A tentative schedule of activities is presented in Appendix E.)

These themes represent the focal points where SIRTF EPO can make substantial contributions to the NASA's education and public outreach efforts. They have been chosen partly by virtue of either the content of the SIRTF science program, the state-of-the art technology incorporated into the SIRTF design, or by the simple fact that the mission represents one of the pillars of NASA's widely-recognized "Great Observatories" program. The inspiration and motivation that will guide the development of individual EPO modules and programs is offered by a series of national education standards (to be summarized in Section 3.2).

To provide proper evaluation of the intellectual content of the themes, SIRTF EPO has already solicited numerous comments pertaining to this Plan from various meetings involving teachers, science educators, and professional scientists. Furthermore, useful comments have been received during the course of individual meetings with the Directors of NASA's EPO Forums (see section 4.1) and with members of NASA Broker/Facilitators (B/F). As the detailed implementation plans unfold over the next year, SIRTF EPO recognizes the value of frequent assessment. To that end, we expect to form an EPO Advisory Group to provide a periodic review of SIRTF EPO plans and activities. Moreover, it is anticipated that a comprehensive review of the SIRTF EPO Plan, especially those components that are to be implemented prior to launch, will be externally reviewed in the context of a SIRTF EPO Critical Design Review, to be conducted in about one year.

3.1 Introduction

The SIRTF keys described in Section 2 -- combined with the needs of educators, the expertise of the SIRTF team, and the national education standards -- suggest various themes where SIRTF can make the most valuable contributions to NASA's space science EPO program. As mentioned previously, SIRTF will concentrate its EPO efforts on filling voids in the present “literature,” rather than reinventing existing curricula and materials.

The themes outlined here have been presented and discussed with scientists and educational representatives in the following venues.

- September 1997: kick-off meeting of the *Solar System Exploration* Forum at JPL
- October 1997: JPL/IPAC SIRTF EPO Workshop
- November 1997: inaugural EPO meeting of representatives from each of the Origins missions at the *Origins* Forum at STScI
- November 1997: meeting with the *Structure and Evolution of the Universe* Forum Director at SAO
- December 1997: meeting of scientists, managers, and industrial contractors at an *Origins* Public Affairs Office meeting at NASA-GSFC
- January 1998: meeting with the EPO Director at the AXAF Science Center in conjunction with the Washington meeting of the American Astronomical Society (AAS)
- April 1998; Fourth Annual Pre-College Education Workshop for Scientists and Engineers, hosted by the Space Science Institute, a NASA-designated B/F
- Continuous: discussions with representatives from the SOFIA program and the Astronomical Society of the Pacific

Enthusiastic responses in each of these meetings lead us to believe that the SIRTF EPO program, while institutionally established within the past month, has already identified a compelling nucleus of themes to develop over the coming years.

In assessing the needs of educators and students, we have taken the first steps in establishing dialogues with professional educators. Useful discussions have already been held between members of the SIRTF EPO team and with teachers in the Los Angeles Unified School District, and in suburban Los Angeles. However, we also intend to establish a broader and more formal means of soliciting input on the best ideas to pursue with our finite resources, in consultation with the JPL Educational Affairs Office and with NASA’s network of Forums and B/F. In all cases, our goal is to focus on what educators need -- both in an intellectual sense and in a materials sense. We will rely on K-13 education professionals, in association with the EPO Forums and B/F to provide guidance on the information, ideas, and product formats that will be most useful and understandable. Furthermore, SIRTF will strive to develop products that emphasize experiential (hands-on) teaching.

One avenue for promoting a further exchange of ideas is an informal SIRTF EPO Workshop at the SSC involving local and regional teachers, tentatively planned for the summer of 1999. Informal discussions will always be a part of any professional meeting, and useful discussions already taken place between the SIRTF EPO team and educators at AAS meetings. These will be expanded upon as SIRTF staff begins to attend the annual National (and California) Science Teachers Association conventions.

The SIRTF team recognizes the importance that NASA/OSS places on the impact of widely disseminated products. Nonetheless, we anticipate developing and testing modules on a local level also. The vast size of the Los Angeles metropolitan area and the network of schools, universities, museums, and observatories in Southern California provide almost limitless opportunities for direct consultations and evaluations of material before gearing up for wider national distribution. The SIRTF EPO teams will explore the possibilities of developing and evaluating content with staff from the nearby Griffith Park Observatory and Planetarium, and with the locally-based Challenger Center at California State University at Dominguez Hills. The geographically distributed sites of SIRTF's Instrument Teams (Cambridge, Ithaca, Tucson) also offer the potential for a broader expanse of local and regional testing of products.

In the following sections, the term *module* is defined as an intellectually coherent set of activities and/or materials devoted to a focused topic. The development of modules will lead to *products* that might include: a classroom lecture and demonstration, an exhibition intended for trade shows and professional meetings, hands-on experiments, an Internet/WWW site, a CD-ROM, a television program, a science museum display, or products such as photographs, slides, or posters. In the context of the present Plan the choices of media and product formats are immaterial (at this early stage, at least). We will instead provide examples of the editorial content that SIRTF EPO intends to develop. Selection of appropriate products and media will be made at later times, after consultations with members of the EPO Forums and B/F, and with other interested experts. Naturally, the formal and informal educational communities will also be consulted as to the best means of product distribution either directly or via the Forums and Brokers/Facilitators.

Before we introduce SIRTF's EPO themes and explore some of the EPO modules we intend to develop, it is crucial that we pause to consider the national science, mathematics, and technology standards that serve as an important framework within which our efforts must reside. Following subsections will then describe three of the themes that the SIRTF EPO team intends to use as the basis for product development. Within each of these themes reside candidates for EPO modules that we regard as suitable for development. This is not necessarily an exhaustive list, but a sampling of concepts that are aligned with the national standards described in the next section, and ones that have been well received in "previews" offered to some of the groups listed above.

3.2 Background: National Education Standards

A series of recent studies has led to the publication and wide dissemination of education standards that are intended to serve as a national vision for establishing a literate populace in areas including science, mathematics, and technology. *These standards establish what every student should know and be able to do in order to be considered literate in these subject areas.* Moreover, these standards are intended to foster an inquiry-based approach to education, an approach where students can actively participate in the learning process and one that extends beyond the rote memorization of textbook facts. While challenging, these standards are attainable. Ultimately, the importance of codifying and promoting these standards will be measured by future generations.

In a polyglot nation whose citizens are immersed in an increasingly complex world of ideas and inventions, and one whose education policies are often established and implemented at local levels of governance, these standards serve as a useful beacon in the pursuit of a common level of literacy and competence. The standards guiding the definition of SIRTF EPO modules have been developed by independent groups and are briefly summarized in the following subsections.

3.2.1 Science Standards

The *National Science Education Standards* (NSES) were published in 1996 by the National Research Council, the principal operating agency of the National Academy of Sciences. They resulted from a multi-year study involving hundreds of individuals and of groups, including teachers, administrators, parents, curriculum developers, college/university faculty, scientists, engineers, and government officials. The NSES extend beyond what might normally be regarded as the central tenets of science: observing, inferring, and experimenting. They are intended to actively engage students in a "hands-on" experience.

The NSES are organized broadly into six types of standards, all of which are to be pursued with equal vigor by the breadth of the educational community. They are:

- Science Teaching Standards
- Professional Development Standards
- Assessment Standards
- Science Content Standards
- Science Education Program Standards
- Science Education System Standards

Each of these sets is intended to govern the unifying approach to implementing the NSES. However, each of the constituencies that comprise the nation's education system (e.g., teachers, policy makers, scientists) might possess the skills and influence that are utilized most effectively in certain areas. Since the SIRTF program is ultimately the result of its scientific motivation, we will concentrate on the Science Content Standards in formulating the appropriate EPO modules for development. However, the actual implementation of some modules will most likely be done with partners selected from the community of pre-college and college teachers, and from such informal education centers as planetariums and museums. This process will clearly involve educators in a way that will promote many of the NSES Professional Development Standards. This will be especially relevant for those materials pertinent to the EPO concepts that extend beyond the science realm and engage teachers in learning about the ways in which science is conducted (details in Section 3.5). Some of the methods of engagement with these experts will be described as the modules are introduced in subsequent subsections.

The NSES Science Content Standards (NSES/SCS) outline what students should know, understand, and be able to do in the natural sciences during the course of K-12 education. There are eight categories of standards in the NSES/SCS, most of which are segmented into three levels of education level (K-4, 5-8, 9-12) for further specificity of contents. One of the categories is Life Science, which is not directly relevant to SIRTF's EPO efforts (although it presumably will be for future NASA Origins missions), and will be omitted from further elaboration. Another category is "Unifying Concepts and Processes," which describe a single set of K-12 conceptual and procedural schemes that permeate all of the NSES/SCS categories. These integrated schemes are: (a) systems, order, and organization; (b) evidence, models, and explanation; (c) change, constancy, and measurement; (d) evolution and equilibrium; and (e) form and function.

The six other categories and their recommended science content standards are listed in Table 1. For the moment, ignore the parenthetical numbers; their meaning will be revealed in Section 6.

3.2.2 Mathematics Standards

The *Curriculum and Evaluation Standards for School Mathematics* were developed by the Working Groups of the Commission on Standards for School Mathematics and were published in 1989 by the National Council of Teachers of Mathematics (NCTM). The standards were designed to establish a broad framework to guide reform in school mathematics in the 1990s.

The Standards introduces a vision of what the mathematics curriculum should include in terms of content priority and emphasis. In effect, they are statements of what is valued and represent a set of tools for judging the quality of mathematics curriculum or methods of evaluation.

The standards are organized into four distinct sections: Grades K-4, Grades 5-8, Grades 9-12, and Evaluation. A summary of the grade-specific standards is presented in Table 2.

Each of the curriculum standards enumerated above includes more detailed pedagogical goals. A complete listing of these goals is obviously beyond the scope of this EPO Plan. As an illustrative example, however, let us list the content and ability goals pertinent for Grades 5-8, Standard 13 (Measurement). For this Standard, students should: (a) extend their understanding of the process of measurement; (b) estimate, make, and use measurements to describe and compare phenomena; (c) select appropriate units and tools to measure to the degree of accuracy required in a particular situation; (d) understand the structure and use of systems and measurements; (e) extend their understanding of the concepts of perimeter, area, volume, angle measure, capacity, and weight and mass; (f) develop the concepts of rates and other derived and indirect measurements; and (g) develop formulas and procedures for determining measures to solve problems. To the extent that the SIRTF scientists and engineers invoke each of these processes without second thought, the importance of this Standard cannot be overemphasized. Some of the SIRTF EPO modules to presented in this Plan will enfranchise students and teachers to simulate some of the same engineering design decisions faced by the SIRTF team, and to learn about how scientists quantify and portray their data.

In addition to these curriculum standards, the NCTM report includes Evaluation Standards. The standards that are relevant to student assessment include mathematical power, problem solving, communications, reasoning, mathematical concepts, mathematical procedures, and mathematical disposition. These goals will be ubiquitous in the EPO modules designed to let students comprehend the scientific portrayal of data, and the ability to analytically examine and interpret SIRTF data.

3.2.3 Technology Standards

As we approach the dawn of a new century and millenium we find that technology plays an increasingly crucial role in society. The International Technology Education Association (ITEA) is one of many groups citing the importance of technology education, and encouraging the development of dynamic problem-solving and design-based programs that enable students to gain experience working with a variety of technological devices and processes.

A landmark ITEA report, *Technology for All Americans: A Rationale and Structure for the Study of Technology,* was published in 1996 with support from NASA and NSF. This document described a clear vision of what it means to be technologically literate, how this literacy could be achieved at a national level, and why it was important to the citizenry. A second phase of the ITEA effort is devoted to development, validation, and publication of content standards for technology education in grades K-12, with assessment benchmarks at grades 2, 5, 8, and 12.

These standards will not be published until thorough reviews and a consensus building process has been completed. The public release date of *Standards for Technology Education* is presently anticipated in March 1999. However, the second draft of the document is currently available online for electronic review. Because it is a draft version of the document, and is subject to alterations and editing, the ITEA will not permit printing of the draft document. Given the fact that this is now the second draft, it is probable that the final published content standards will closely resemble the version presently posted for review and comment. Table 3 presents a compendium of the content standards for technology education (1998 April 1 draft).

The standards for technology education establish what every student should know and be able to do on order to be technologically literate; that is, possess the ability to use, manage, and understand technology. The content standards indicate the knowledge and processes essential to technology and that should be taught and learned in school.

The scientific legacy of SIRTF will ultimately be a testament to the technological innovations incorporated into the mission. The entire field of infrared astronomy is undergoing a renaissance due to the huge improvements in detector technology, building upon the heritage established with military investments. Moreover, SIRTF has twice been redesigned and rescoped to accommodate the reduced fiscal resources available. However, clever choices in orbit and engineering architecture have enabled SIRTF to maintain its scientific viability at a small fraction of its originally envisaged cost. The enabling technologies that have brought IR astronomy to the forefront of astronomical research will form the basis of some exciting and insightful EPO modules.

3.3 The Concept of Temperature

An early perusal of existing resources indicates that there may be plenty of materials already devoted to the electromagnetic spectrum. (Nevertheless, some teachers have conveyed to us that there is a lack of materials about "light"!) SIRTF EPO will not ignore the EM spectrum, but chooses to concentrate on an aspect that is particularly relevant and physically meaningful to infrared astronomy (and to the public in many environmental and engineering contexts) -- the concept of temperature.

3.3.1 The Electromagnetic Spectrum

The approval of SIRTF, and the eagerly anticipated completion of the "Great Observatories," will fill an important gap in NASA's observational coverage of the EM spectrum. What is often under-appreciated is the immense amount of information we glean from the cosmos by observing outside the narrow band of visual wavelengths. Information about objects in the cosmos is gleaned from the radiation emitted at all wavelengths. Until this century, human understanding of the Universe was severely limited by the study of radiation from a mere sliver of the EM spectrum – the visible bands.

The fundamental importance of visual radiation will first be established via a new module, *"The Nature of Light,"* courtesy of an IDEA grant recently awarded to a member of the SIRTF EPO team (Marcia Rieke). This module will develop a laboratory exercise for middle-school students at a Los Angeles magnet school to quantitatively examine the nature of light. Using a silicon photodiode sensor, students will learn about the inverse square law of radiation, and see how the application of Wien's law allows astronomers to remotely determine the temperatures of planets and stars. Apart from this module and its implicit relationship to the EM spectrum, the SIRTF EPO efforts will concentrate on the importance of infrared radiation, and on how it can be used to reveal the temperature of celestial objects.

3.3.2 Infrared Radiation and Temperature

SIRTF's observational "bandwidth" is some 30 times greater than the relative extent of the visual bands, and hence the infrared regime will reveal many aspects of phenomena that can only be realized outside the visible window. This would not matter, of course, if the newly explored infrared were devoid of interesting features. But we know that the opposite is, in fact, true!

Many of the most fundamental mysteries of astronomy can only be studied in the infrared. Why?

(1) The Hubble expansion of the Universe redshifts the optical radiation from distant objects into the IR region of the spectrum. Hence, IR observations can probe the Universe as it was when it was only a fraction of its present age.

(2) Dust is a very effective absorber and re-radiator of optical and ultraviolet light. Therefore, much of the radiant energy in the Universe is found in the infrared.

(3) Many of the Universe's constituent parts (such as galaxies and stars) are found in dusty environments. The only way to peer into the obscured cocoons of star formation and into the heart of dusty galaxies is through infrared eyes.

(4) The Universe is a cool place! Many astrophysical phenomena are relatively cool (planets, interstellar gas and dust), and hence radiate primarily at IR wavelengths.

(5) The infrared region is home to a very large number of the most important atomic and molecular transitions. The resulting IR spectral features are important diagnostic tools for understanding physical conditions and processes in planetary atmospheres, interstellar clouds, and in distant galaxies.

(6) As the *Origins* program will seek to exploit, the mid-infrared region is where the elementary spectral lines indicative of life-sustaining environments are located.

The SIRTF EPO program will elaborate on these factors, and also strive to communicate how information gathered in this regime can be supplemented with data from other wavelengths to provide a "complete picture." This will be done through development of a module titled, *"More Than the Eye Can See: Infrared Radiation."*

A portable infrared television camera will be the central element of this module. The camera looks much like any other (optical) TV camera, except that its imager is a lead zirconate array with an effective 200 x 200 resolution elements. This detector is sensitive to mid-IR radiation in the wavelength range of 8-14 microns. Infrared radiation is not so dissimilar from visual radiation that one has to completely abandon the comfortable precepts established through everyday experiences. It enables the observer to "see" images of thermal radiation, and to visually delineate between common-day precepts such as *hot* and *cold*. The camera has already been taken to various classrooms and demonstrated before awed youngsters. The camera was also a central part of the SIRTF Project exhibit booth at the recent Washington AAS meeting. Even professional astronomers, whom one might perceive as being jaded, were impressed by the simple display. The camera will be traveling frequently as part of exhibits and as an essential element of the classroom demonstrations.

At this point, the complete display consists of the camera, a box containing an incandescent light source, a separate non-thermal electro-luminescent light, and a (hair care) curling iron. With a sheet of plastic that simulates dust and a pane of Lexan that simulates the Earth's atmosphere, one is able to demonstrate the essential aspects of radiation transmission and thermal energy. Apart from seeing themselves at 10 microns, the most popular demonstration for adults and children is simply to place a human hand on the cover of a book, remove the hand, and see how long (and deep into the book's contents) the IR image of the handprint can be detected! One of the first things the SIRTF EPO team will undertake is a more sophisticated IR camera demonstration for classrooms, professional meetings and conventions, and possibly for incorporation into the redesigned SIRTF Internet site (see Section 5). It will demonstrate not only the differences between infrared and visible radiation, and their astronomical contexts, but will also touch on the greenhouse effect and how home insulation is used to promote energy conservation. The IR camera module will complement the module already under development and discussed in the previous subsection.

3.4 From Photons to Knowledge

The revolution in human understanding of the cosmos, particularly in the 20th century, has been dramatic, and has far-reaching implications that stretch from physics to theology. What makes astronomy even more amazing than the mind-boggling phenomena routinely studied is the immensity of it all. We may not know the size of the Universe to within a factor of two, but we do know that it is too large to ever permit *in situ* measurements for all but our local cosmic neighborhood. Unlike the other "hard sciences," virtually everything we have come to learn about the Universe is by virtue of remote sensing. The messengers of knowledge, of course, are photons. The "alchemy" of how scientists turn photons into knowledge will be the source of inspirationally educational modules.

3.4.1 Radiation as Messengers

Consider for a moment the simplest atom in the Universe – hydrogen. A magnetic dipole transition between the two ground-level states of hydrogen results in an emission line that is easily detectable by most radio telescopes. By measuring this elementary spectral line in spiral galaxies, astronomers can tell you how rapidly the galaxy spins about its axis, the amount of neutral hydrogen in that galaxy, and (with a few simple assumptions) the total mass of the galaxy! This example wonderfully illustrates the way in which scientists, by simply collecting photons, can elucidate the nature of the Universe's mysteries.

There are many analogous examples attesting to the value of images and spectra, stretching from radio waves to gamma rays. In infrared astronomy alone, scientists' ability to measure and interpret radiation allows them to study objects as diverse as cosmic dust and primeval galaxies at the edge of the observable Universe. One can persuasively argue that the keys to determining the origins of all structures in the Universe, from planets and solar systems to stars and galaxies, reside in the information contained in the infrared. The inescapable facts that account for the importance of studying IR photons were enumerated in Section 3.3.2.

We will develop a module, *"Decoding Radiation,"* that directly explores the theme of converting photons to knowledge, emphasizing the types of observations that will be carried out by SIRTF. This module will exercise not only the NSES Science Content Standards, but will also be directly relevant to the NCTM Mathematics Standards. We will build upon some of the precepts introduced in Section 3.3, and show, for example how astronomers will use SIRTF to:

- study multi-band imaging and luminosity ratios (colors) to search for brown dwarf candidates, and how follow-on observations can be used to identify confirming spectral signatures;

- conduct photometry of nearby stars to search for an excess of IR radiation (beyond what is expected from the stars themselves), and hence infer the existence of planetary debris disks, and to perform high-resolution spectroscopy to characterize the structure of these circumstellar disks, with implications that will likely impact the "new" field of extra-solar planetary research;

- perform a large sky survey at far-infrared wavelengths to search for ultraluminous infrared galaxies, and to use direct (spectroscopic) means of determining their redshifts (and hence distance), helping to unravel the evolutionary history of these objects; and

- carry out a very deep near-infrared imaging survey of the distant Universe, and using indirect (photometric) methods for estimating redshifts, and then perform a complementary far-infrared imaging survey of the same area to compare the number of galaxies observed with estimates from theoretical models.

These are but a handful of the types of scientific investigations that will be carried out by astronomers using SIRTF. The goals of any EPO modules developed along these lines will be to clearly identify what information follows directly from the measurements, what assumptions (if any) must be made to support the data analysis, and how the validity of those assumptions can be tested or verified. The examination of *inductive reasoning* in the module *"Critical Thinking"* will lead to a fascinating journey into how information is processed and how critical thought defines the essence of the scientific process.

3.4.2 How Scientists Visualize, Portray and Interpret Data

The general public is accustomed now to seeing wonderful color images of astronomical phenomena in books, on television, and in newspapers. Yet if one were to set up a small amateur telescope in the backyard, or perhaps visit a local observatory for an evening of public observing, the fortunate amateur might aim their gaze at a nebula or galaxy (or any celestial source with extended emission) and see a…dim.…gray…..fuzzy……blob! The human eye may be the most prized of our senses, but its dynamic range cannot fully reveal the splendors of the Universe, even for nearby objects. The routine use of electronic detectors and digital computers not only produce stunning photos, but also permits scientists to display information in ways that can filter the unneeded (or less important) information, and to emphasize the truly valuable data. In fact, two scientists might collect the same photons from the same object, but choose to display the data differently in order to study separate characteristics of that source. The physiological and psychological aspects inherent in rendering data make for an interesting theme that the SIRTF team will develop as part of its EPO program in the module *"Visualizing Data."* Once again, this module will be constructed so as to focus on relevant NSES and NCTM education standards.

Some aspects of data visualization will demonstrate how space science connects with every-day life. For example, the digital photography revolution and its connectivity to personal computers (for display, enhancement, and even manipulation) provides the general public with the same tools that have been used for years by research scientists – whether they be astronomers or physicians.

3.5 The Scientific Process

Why do some scientists spend most of their professional careers working on a project like SIRTF? That is the question posed recently by an incredulous youngster quizzing a NASA astronomer. The astronomer did not have the heart to tell the impressionable questioner that many of us spend out entire careers seeking the answer to just a handful of questions!

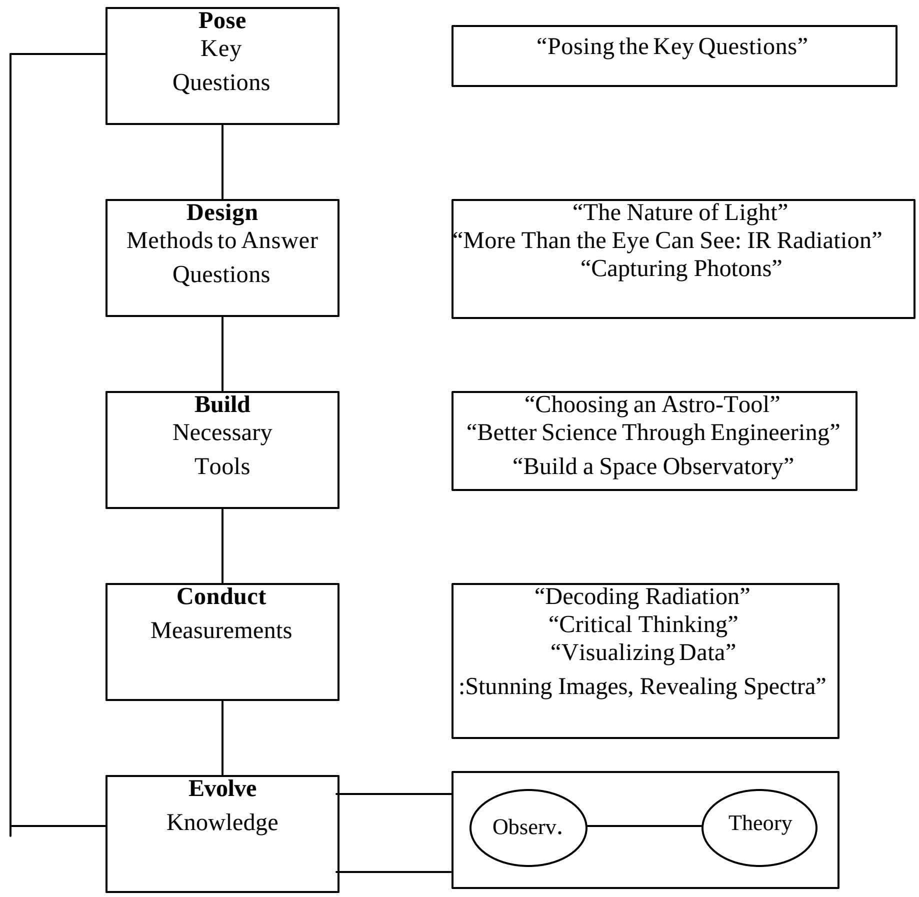
Much of the American public has been led to believe that science is defined by the "Final Result." Many scientists, and their supporting government agencies, are proficient at disseminating their results. Most are less successful in conveying that the process itself is science, and it is this eternal quest for knowledge that helps define us as humans.

Many years ago, *The Economist* weekly newsmagazine produced a survey (a special insert) on science. The statement was made that scientists usually work hard, they trade gossip around the water cooler, they are argumentative and disagreeable with colleagues, and -- as an afterthought -- they occasionally make discoveries! The point of this anecdote was to illustrate that scientists share the same experiences as bricklayers and bankers. A collateral, but by no means lesser, benefit of exploring the scientific process is the opportunity to portray space scientists as simply a part of society at-large. The worldwide fascination with the exploits of the *Mars Pathfinder*, and its anthropomorphic *Sojourner* rover, has been well documented. But who can possibly predict the impact, perhaps decades in the future, of children seeing a new breed of young scientists, engineers, and technicians (wearing Hawaiian shirts, no less!) in their living rooms each night on television?

The National Center for Education Statistics recently published a report card, "*National Assessment of Educational Progress (NAEP): 1996 Trends in Academic Progress.*" The NAEP assessed the performance of a nationally representative sample of 30,000 students in Grades 4, 8, and 11. Among 13-year olds, for example, only 12% possessed some detailed scientific knowledge and could evaluate the appropriateness of scientific procedures, and an infinitesimal fraction could infer relationships and draw conclusions using detailed scientific knowledge. The corresponding fractions among 17-year olds were 49 and 11 percent. Any credible EPO program must reach beyond the strictest scientific results, and attempt to address some of these disturbing numbers. By doing so, we feel that the SIRTF efforts can not only enhance the implementation of national science, mathematics, and technology standards, but are confident that it will promote the NSES Standards for the Professional Development of Teachers of Science. We fully intend to invite pre-service and in-service science educators to participate in the process that we call *science*.

Figure 1 schematically illustrates the primary elements of the scientific process that we intend to elucidate. Some of the proposed EPO modules introduced in subsequent sections are listed in the right-side margin.

Figure 1: The Scientific Process



3.5.1 SIRTF's "Big Four" Science Objectives

Every scientific endeavor is the result of humankind's unquenchable thirst for knowledge. Today, those quests often require extremely complex and expensive tools for conducting measurements. To identify and select the "best-of-the-best" projects that deserve significant public expenditures, it is crucial to formulate and elucidate the "key scientific questions" for which a particular tool can provide useful data and (hopefully) understanding. It is this fundamental starting point that will serve as the basis of a module called "*Posing the Key Questions.*"

SIRTF's scientific agenda was re-evaluated and re-defined following the second budget-driven Project rescope in 1994. The SIRTF Science Working Group conducted a careful re-examination of SIRTF's science objectives. The goals of the study were to identify those topics deemed to be of high scientific priority and for which a cooled meter-class telescope with background-limited detectors and multiple instruments could make substantial intellectual contributions. SIRTF was then re-designed to effectively address these scientific objectives, while providing the capabilities to permit the scientific community to pursue other topics of interest also.

This process led to the definition of four key science objectives for SIRTF:

(1) the search for brown dwarfs and super-planets,
(2) the discovery and study of protoplanetary and planetary debris disks,
(3) the study of ultraluminous galaxies and active galactic nuclei, and
(4) the study of the early and distant Universe.

Some of the key questions of wide astrophysical interest that pertain to these objectives are:

- How ubiquitous are brown dwarfs? Can they account for much of the "dark matter"? What is their spatial distribution? Do they play an important role in the dynamics of the Galaxy and the Universe?

- How common are (proto)planetary debris disks around main-sequence stars? What are the properties of these disks, and how do they vary with mass, age, and type of star? How do the origin, composition and properties of extra-solar debris disks compare with the dust component of our Solar System?

- What is the evolutionary link between ultraluminous infrared galaxies (ULIRGs) and quasars? At what redshifts do heavy elements form? How do ULIRGs relate to the epoch of galaxy formation?

- How do galaxies form and evolve? How does star formation evolve with time in the distant Universe? What is the nature of the faint extragalactic IR background?

The answers to each of these questions have profound implications on the collective state of astrophysical knowledge. The fact that many of the answers can only be revealed through infrared observations mandates a large, space-based IR observatory -- SIRTF.

Every science discipline has its set of Key Questions. The SIRTF EPO team will concentrate on how one might take these questions, and the universal laws of physics, to derive the means for pursuing answers. Of course, emphasis will be placed on SIRTF's "Big Four" objectives, and on how the more detailed questions drive the design and capability of any Observatory design.

3.5.2 Technology Enables Science

Apart from the scientifically compelling motivations behind infrared astronomy, there is a dramatic technological revolution -- still ongoing -- that has done much to open up the vistas of the IR universe. The remarkable progress made in infrared detector technology has resulted from a synergistic relationship between science and technology -- and between industry and universities. The genesis of this revolution was the investment of hundreds of millions of dollars in infrared array technologies by the US Department of Defense over the past two decades. Military interests in this technology development concentrated on high-background temperature environments and on wavelengths shorter than about 30 microns. As the accumulated technical knowledge has migrated to the civilian world, astronomers have redirected the focus of development towards the goal of low-background, high-sensitivity applications. Impressive progress has been made in developing large-format detector arrays and in supporting electronic readouts at all wavelengths stretching from the near- to the far-infrared.

In less than 20 years, infrared astronomers have seen the state-of-the-art progress from instruments with a handful of discrete detector elements to routinely working with arrays of over one million pixels! One looks back with a mixture of amazement and amusement when recognizing that the incredible legacy of IRAS resulted from a total of 59 detector elements! It is this revolution in infrared detector technology that was primarily responsible for the 1990s being labeled the "Decade of the Infrared."

The SIRTF EPO team will seek to convey the impact that technology developments have had on the pursuit of science in the module "*Capturing Photons,*" with emphasis given to detectors. Here, the term *detectors* will be taken to be the sum total of the magnifying telescope, the instruments selected for studying the collected light, and the solid-state imaging arrays used in the instruments themselves (and the human eye, of course!).

We will also extend the concepts introduced via the infrared radiation module and explain why it is vital to cool infrared telescopes and instruments to within a few degrees of absolute zero. SIRTF's choice of a novel Sun-centered orbit offers the potential of constructing an educational module (perhaps an Internet-based interactive primer) in which students select an optimal orbit themselves. By exploring various possibilities, they will learn about the thermal disadvantages of being close to the Earth, the hazards posed by enhanced cosmic-ray radiation in the Van Allen belts, and the compromises that must be made in operating and scheduling an Observatory in low-Earth orbit.

The choice of orbit enables SIRTF to adopt another innovative scheme: a "warm-launch architecture." SIRTF will break from the traditional paradigm of encasing a large IR telescope in a huge "thermos bottle," or cryostat. SIRTF will instead launch at ambient temperature, cooling only the scientific instruments, and then rely on radiative (passive) cooling in deep space and the effluent from the liquid helium cryogen to cool the telescope to its operating temperature of a few Kelvin. This approach will greatly reduce the mass – and cost – of achieving orbit, and clearly represents the only viable approach to large, low-cost infrared observatories of the future. This clever approaches to selecting an orbit and the launch architecture will be important aspects of the module, "*Better Science Though Engineering.*" The consideration of orbit choices will invoke celestial mechanics and physics, and thereby adhere to important NCTM mathematics and NSES science standards.

The SIRTF EPO team will also develop an Internet module in which students will be provided the basic components of an orbiting observatory (e.g., telescope, radiation shields, instruments, cryostat) and allowed to design their own facility. In a sense, they will replicate what the SIRTF engineers have been wrestling with during the Project's design phase. The module will be designed such that students can learn about the pitfalls of making crucial mistakes (instruments outside the cryostat, for example), and come to appreciate some of the design considerations that all space-borne observatories must face. This module will be expanded to permit students to schedule simulated observations, say constellation by constellation, to understand the concepts of orbital mechanics and viewing constraints. Another added component will be to introduce the idea of ionizing (particle) radiation, how these cosmic rays affect orbiting spacecraft, and how the Earth's atmosphere and magnetic field offer protection. The module, "*Build a Space Observatory,*" will utilize elements contained in the ITEA technology education standards, in addition to the science and math standards cited above.

3.5.3 SIRTF as a Tool

At an elementary level, SIRTF is nothing more than a tool; one of many that astronomers rely on to address the cosmic questions that mystify us all. The general public may not realize that the size of our toolbox is constrained to fit a budget. We have had to be careful, then, in designing the SIRTF tool so that it maximizes its utility within the constrained resources available.

The public at-large has very little, if any, insight into how NASA's tools (observatories, programs) are selected. Are we allowed to develop every tool imaginable? Of course not. Then how do astronomers select the observatories that are built? Who decides which proposals are approved, and which ones are not? The intellectual and programmatic process by which NASA approves mission concepts might make an interesting EPO module, if we find the proper approach. Consider that fact that if the annual costs of NASA's entire space science Enterprise were evenly distributed among all Americans, each person would pay only $7.70 a year. Is this a good investment of tax money? We feel that most Americans would respond, enthusiastically and incredulously: Yes! The faith in their investment would likely be enhanced if they were to realize that only the very best mission concepts ever are approved for flight. We intend to construct a module that offers insight into the deliberative methods used to select the best ideas for flight, *"Choosing an Astro-Tool."*

3.5.4 The Scientific Utilization of SIRTF

While SIRTF is a state-of-the-art infrared observatory, it cannot answer every question that bedevils astronomers. Like any other science tool, its discoveries and findings are often enhanced by, and may even require access to, other data. We will show how an observatory's utility is enhanced by complementary observations collected with other tools, whether they are in orbit, on the ground, or in the air. This synergistic relationship between resources was one of the major selling points for Congressional approval of the "Great Observatories," and we hope to show how SIRTF's observing plans are integrated with those of HST, AXAF and CGRO, and how the ultimate scientific returns are amplified by results from multiple tools.

The SIRTF team also intends to delve into the important distinctions between imaging and spectroscopy. It is often said that pictures sell, and spectra reveal the science. In truth, of course, both capabilities are essential if one hopes to characterize any celestial phenomena in detail. The collection of data from multiple tools, and the distinction between the data often presented to the public (images) and the diagnostic data that are often the most useful to scientists (spectra), will form the basis of a module titled *"Stunning Images, Revealing Spectra."*

3.5.5 The Evolution of Knowledge

Much of the public's perception of the scientific process is limited to seeing enticing photographs and perhaps reading the accompanying article about a fresh discovery or a new result. Rarely, if ever, are they permitted inside the citadel and permitted to see how scientists arrive at these results.

One of the goals of SIRTF EPO is to open the door and let the public see how scientists pursue their craft. The public deserves the opportunity to see the process as it unfolds – both the Socratic debates, and the passionately heated disagreements. Contrary to what is typically packaged into a television program, for example, the path to "true knowledge" is often long and torturous -- if not occasionally bizarre.

Who can ever forget the dramatic retraction of the first "discovered" extrasolar planetary system at an AAS meeting a few years ago, and the accompanying shock and emotion that permeated the convention hall as the lead investigator admitted his mistakes before a large audience? Yes, scientists make mistakes, and the road to knowledge is often littered with wrong turns and dead ends. When the public is asked to evaluate the importance of a science finding, they should also understand the deliberative processes that took place beforehand. Scientific paradigms are continually revisited and often discarded. There is rarely (if ever) unanimous consent for any scientific thesis, and the public is likely to be interested in knowing not only the alternate explanations, but the process by which consensus is built.

Many of the questions posed in Section 3.5.1 are accompanied by differing explanations, fiercely defended by their respective scientists. We will delve into some of the leading explanations for observed phenomena, and elucidate how SIRTF's capabilities can help distinguish between theoretical models. Once the observational data become available starting in 2002, we can witness firsthand how SIRTF data can be used to support or refute ideas (e.g., the explanation of how ultraluminous galaxies are powered). There will doubtless be some surprises, and a need to re-examine commonly held wisdom. The fact that theories are tested, confirmed and often abandoned will form the basis of a module, *"Our Knowledge Evolves."*

There is a critically important aspect of Figure 1 – the scientific process is a loop! We have yet to obtain the definitive view of the Universe, and may never do so. The relevant point is that regardless of any tool's capabilities, Nature will always conspire to introduce new phenomena and new mysteries. We may build the ultimate tool for answering today's perplexing questions, but that same tool is likely to raise even more questions to ponder in the future. And design concepts for an even more powerful tool will already be vigorously debated. While Congress approves large space science programs on an individual basis, NASA space science will be served better when society recognizes and appreciates "the loop," and the fact that astronomers' study of the cosmos is an ongoing endeavor.

Once SIRTF begins operations, we will be in position to evaluate the extent to which the new data will answer the questions posed earlier. Furthermore, any discoveries made by SIRTF will lead to new sets of unanswered questions. By the end of the mission, we will likely have developed a new and revised set of "Key Questions" for the next space IR telescope to address. This evolution of knowledge will form the basis of an EPO module. That module will also examine the interplay between observations and theory, and how the two continually challenge and impact the other.

3.5.6 A Novel Program for Public Participation

The most impressionable means of conveying SIRTF's scientific process can only be through direct hands-on experience. We cannot recapture the last 25 years of debate and design for public consumption, nor is it likely we would want to. However, the SIRTF Project offers the opportunity to implement a novel program of public participation in the mission. The central tenet of this module would set aside a small fraction of SIRTF observing time, under the auspices of the SSC Director, and to permit a segment of the general public to utilize this time. The appropriate amount of time remains to be determined, and will have to be studied and negotiated with the SSC Director; however, it is likely to be no more than a few hours.

Simply letting the public through the front gates as the data comes down from the satellite defeats the purposes described earlier in this Section. The SIRTF EPO team proposes, instead, to identify a "group" of ninth graders within the next year or tenth graders in 1999. In this context, a "group" might be a local class of students, it might be a collection of students throughout the region, or it might even be a national network of cohorts joined via the Internet. The targeted audiences have not yet been identified, but could include a mix of students at science/technical magnet schools and under-represented groups of students. The EPO goal of this endeavor would be to follow this group through launch and the first year of operations, providing an inquiry-based insight into all of the major elements of carrying out a science investigation – planning, target selection, telemetry, data processing, and interpretation. Another possible means to engage the public in a highly leveraged way would be to designate a medium through which this program could be implemented. As will be seen in Section 4.5, the new California Science Center might be the ideal institution that can effectively serve as the intermediary in this proposed program.

There is a JPL precedent for public involvement in a space science mission -- KidSat. This project involved several public schools around the country in the design, flight, and operations of a space-borne camera on the Shuttle. Students in middle school and high schools were formed into teams for mission planning, downlink data processing, and data analysis. Student operations teams relayed requests for imaging of specific areas during orbital operations of the Shuttle. The data were then distributed via the Internet, analyzed by students, and subsequent results presented by the students at press conferences. The World-Wide Web (WWW) was utilized to design mission sequences, to archive the data acquired during the flights, and for query/retrieval from a database. The project, undertaken in conjunction with educators and designed with tightly focused objectives, was judged to be highly successful.

Clearly, the idea of permitting the public to plan, observe, and analyze a few hours of SIRTF observational data needs to be carefully studied before implementation. The "amateur astronomers" program on HST was deemed by many to be a failure for a variety of reasons, but primarily because these programs were expected to conduct world-class science. As a consequence, the handful of approved investigators placed an enormous drain on the expert staff at STScI. Given the relatively small amount of funding available for SIRTF's pre-launch operations development, we clearly cannot repeat the HST experience. *Therefore, the primary goal of this module is to offer a "hands-on" insight into the scientific process, and <u>not</u> necessarily to produce publishable science results*. For now, we refer to this candidate EPO module as *"Lifting the Science Veil."*

Skeptics are likely to criticize the possibly narrow impact such a program might have, especially if done only at the local level. The counter argument is that the novelty of the program is likely to attract much wider media attention. Many of the details need to be studied and debated. There is no guarantee that this program can surmount the fiscal and political issues that remain to be resolved. However, we feel that this unique program offers the potential for favorable reactions in the court of public opinion, and are determined to carefully explore its feasibility.

4. An Integrated Approach to EPO

The NASA/OSS EPO Implementation Plan introduces the concept of an "ecosystem" for space science education in the US. This comprehensive network of producers (the NASA missions and programs), archivers and disseminators (the Forums), education and teacher facilitators (the Brokers/Facilitators) and individual NASA-supported scientists is intended to foster a wide variety of highly leveraged EPO activities, and to minimize repetitious overlaps in functionality and product development. SIRTF's approach to EPO will be tightly integrated with all relevant entities pursuing the NASA/OSS goals in EPO. A closer look at some of these symbiotic relationships is provided below.

4.1 Integration with OSS Forums

NASA/OSS has recently anointed a series of EPO Forums, aligned with the four themes that comprise NASA's Space Science Enterprise. They are:

- *Astronomical Search for Origins and Planetary Systems* Forum, commonly referred to simply as the "Origins Forum," based at the Space Telescope Science Institute in Baltimore, under the direction of Drs. Terry Teays and Carol Christian.

- *Structure and Evolution of the Universe* Forum (the SEU Forum), based at the Smithsonian Astrophysical Observatory in Cambridge, under the direction of Dr. Roy Gould.

- *Solar System Exploration* Forum (the SolSysEx Forum), based at the Jet Propulsion Laboratory in Pasadena, under the direction of Dr. Steve Saunders.

- *Sun-Earth Connection* Forum (the SEC Forum), a collaborative effort based at NASA-GSFC and at UC-Berkeley, under the co-direction of Drs. Rich Vondrak and Isabel Hawkins.

The role of these nascent Forums is still being defined, but they will likely act as central clearinghouses of information relevant to the effective dissemination and archiving of EPO materials, and to research leveraging opportunities. NASA/OSS is still relying on the individual missions and programs to provide the bulk of the value-added EPO content and the editorial expertise required for developing educationally worthwhile products.

Inspection of SIRTF's "Big Four" science objectives (Section 3.5.1) immediately reveals that the science of SIRTF crosses the phenomenological boundaries established by NASA's Forum structure. SIRTF will clearly have much to offer to each of the first three Forums listed above, and will work with each of these entities in developing EPO materials. Personal contacts have already been established with each of the relevant Forums, and the EPO themes described in Section 3 have been enthusiastically endorsed by these Forums.

In addition to the EPO Forums, NASA/OSS has competitively bid and selected five regional Brokers/Facilitators to serve as facilitators for people seeking information and connections. The Brokers will have close ties to the education community, and hence are well-positioned to arrange alliances between educators and scientists. These Brokers/Facilitators are assumed to have an intimate knowledge of what educators need, and how best to distill space science results into useful products and services. Because of previously established working relationships and our participation at a recent Workshop, the SIRTF EPO team intends to rely partly on the expert staff of the Boulder-based Space Science Institute (one of NASA's B/F) on advice pertaining to the most appropriate intellectual content and format for product development. We also intend to seek similar advice from a broader roster of experts, including NASA scientists and educators affiliated with the NASA EPO Forums, from staff at relevant informal education centers, and from the EPO staff associated with some of the programs and projects listed below.

4.1.1 Origins Forum

At NASA Headquarters, SIRTF' program administration falls in the realm of the *Astronomical Search for Origins and Planetary Systems* program in the Office of Space Science. While the OSS themes do not necessarily "own" space science missions, the Origins theme will be a significant underpinning of SIRTF's science program. NASA's Origins program was established to address these fundamental questions:

- How did galaxies form in the early Universe, and what role do galaxies play in the appearance of planetary systems and life?
- How do stars and planetary systems form, and are there life-sustaining planets around other stars?
- How did life originate on Earth, and does it exist elsewhere in the Universe?

The four key science objectives of SIRTF map neatly into the first two fundamental Origins questions, and therefore the SIRTF EPO efforts will be tightly coupled with the other science missions within the Origins program.

There are three additional motivating factors to recommend a close integration of SIRTF's EPO program with those of the *Origins* Forum. First, the *Origins* Forum is co-located with the 20-member staff of the STScI EPO Office, and is likely to synergistically benefit from this proximity. The staff at STScI has done a laudable job of establishing a model program for NASA EPO. Just as SIRTF's low-cost flight and science operations will rely on the heritage of infrastructures and tools developed at STScI, there is little question that SIRTF's EPO program can build upon the solid foundation established by STScI.

Second, the installation of the *Near-Infrared Camera and Multi-Object Spectrograph* (NICMOS) instrument in early 1997 added near-infrared capability to HST, permitting observations out to 2.5 microns. SIRTF's wavelength coverage will essentially start at that point, and run well into the far-infrared. The ability of SIRTF to extend the initial discoveries of HST/NICMOS is obvious, whether it be star formation in dusty cocoons, or the exploration of high-redshift galaxies. We note that Marcia Rieke, a key player in the SIRTF EPO program is also the Deputy Principal Investigator for NICMOS.

Finally, SIRTF is an important scientific and technological precursor to future Origins missions such as the *Next Generation Space Telescope* (NGST) and the *Terrestrial Planet Finder* (TPF). As such, it is anticipated that SIRTF's EPO activities will introduce certain concepts (e.g., passive cooling of telescopes; the importance of mid-infrared spectroscopy for identifying molecular species like water, ozone and methane) that can be followed up in the future by these other missions.

4.1.2 SEU Forum

NASA's *Structure and Evolution of the Universe* strategic plan for 2000-2020 identifies three fundamental Quests for the coming decades:

- To explain structure in the Universe and forecast our cosmic destiny;
- To explore the cycles of matter and energy in the evolving Universe; and
- To examine the ultimate limits of gravity and energy in the Universe.

These quests represent issues of broad scientific and popular appeal. SIRTF's "Big Four" science themes clearly address the first two Quests inherent in NASA's SEU theme, and may offer some insight into the third.

The SEU Forum Director and the Director of the co-located AXAF EPO Office have both stated interest in jointly pursuing EPO initiatives of common interest with SIRTF, and it is anticipated that our efforts will be linked appropriately. One interesting concept that will be pursued is how radiation of such different wavelengths (X-rays and infrared) can reveal different aspects of the same object, and provide a more complete understanding of its underlying physical processes.

4.1.3 SolSysEx Forum

The US planetary astronomy community has stated that SIRTF will be an invaluable tool for exploring a variety of topics, including the study of planets and comets, and the characterization of faint objects in the Kuiper Belt at the distant edges of the Solar System. SIRTF's study of extrasolar debris disks and super-planets will offer insight into the formation of our own Solar System.

The SIRTF Science Working Group and the Community Task Force include representatives from the planetary community. (The latter group is a community-based group responsible for debating policies and providing advice on issues pertinent to the efficient scientific utilization of SIRTF.) Based on the expressed interests in SIRTF, and on the precedents being established with ISO, it is conceivable that about 10% of SIRTF's competitively selected Guest Observer science program will ultimately be devoted to Solar System targets.

The co-location of the SIRTF Project Office and the SolSysEx Forum at JPL has made it rather simple for the Project to keep abreast of activities being considered within the Forum. The fact that many of JPL's planetary missions rely on remote sensing, and that some carry infrared instruments, immediately suggests a common bond between our programs. Some of the ideas illustrated in Section 3 have been discussed with representatives of the SolSysEx Forum, and it is likely that collaborative activities will be established.

4.2 Integration with other OSS Missions/Programs

In addition to the programmatic basis for integrating SIRTF's EPO efforts with the NASA/OSS Forums, there is compelling reason to do the same for related space science missions and programs. This is particularly important in selecting the intellectual concepts from which EPO products will be developed, since NASA/OSS and the network of Forums/Brokers will still rely on each component mission to identify the areas where they can make the biggest impact per unit cost. It is assumed that SIRTF EPO will consult regularly with corresponding colleagues at STScI, and seek opportunities to leverage into the established HST infrastructure. The focus of this section, however, will be on how SIRTF will work with its "sister" program, and with a pair of smaller infrared programs based primarily at JPL.

4.2.1 SOFIA

The most obvious partner for SIRTF EPO, at least among major new programs, is the *Stratospheric Observatory For Infrared Astronomy* (SOFIA), the next-generation airborne platform for IR astronomy. SOFIA will incorporate a 2.5-meter diameter telescope into a Boeing 747 airplane and will conduct ~160 observational flights annually from its home base at Moffett Field, California (and occasionally from remote locations in Hawaii and from sites in the Southern Hemisphere). SOFIA's complement of interchangeable instruments will provide imaging and spectroscopic coverage from the near-infrared into the submillimeter regime. Initial deployment is slated for 2001, within months of the SIRTF launch.

SIRTF and SOFIA represent two-thirds of the major initiatives recommended by the National Academy of Sciences in its decadal "Bahcall Report." Their scientific complementarity, geographic proximity and operational simultaneity form the basis for a natural coupling of EPO programs. Where SIRTF's great sensitivity and efficient observational schemes lend themselves to both unbiased and targeted surveys (a concept that is institutionalized via community-led Legacy Science projects), SOFIA is well suited for studying individual targets. SOFIA's ability to conduct long-wavelength spectroscopy and polarimetry will be essential in obtaining the "complete picture" for objects discovered by SIRTF. Moreover, many of the scientists who will ultimately use SIRTF were regular investigators aboard the *Kuiper Airborne Observatory* (KAO), the predecessor to SOFIA. This will make an interesting story that will no doubt be elaborated upon in the SIRTF EPO program.

Airborne astronomy has been at the forefront of marrying educational programs with astronomical research as it is being conducted, epitomized by the *Flight Opportunities for Science Teacher EnRichment* (FOSTER) program that allowed pre-college teachers to obtain first-hand research experiences on KAO flights. SOFIA's greater carrying capacity offers the potential for an expanded program of in-flight educational programs, and SIRTF EPO will be seeking collaborative opportunities with their SOFIA colleagues.

The complementary scientific goals of SIRTF and SOFIA, and their programmatic and geographic proximity have already led to EPO discussions between SIRTF and SOFIA teams. SIRTF intends to jointly develop appropriate EPO programs devoted to infrared astronomy with the SOFIA EPO program, and their collaborators – the Astronomical Society of the Pacific (ASP) and the SETI Institute.

One possibility for collaborative development is the production of posters, videos and television documentaries pertaining generally to infrared astronomy. Exploratory discussions have already been held on the joint development of an educational poster, *"Lifting the Cosmic Veil."* The SIRTF EPO team has also been contacted by an independent television production company seeking to completely develop and film a 30-minute program on infrared detectors for broadcast on the Discovery cable channel. With wide-ranging applicability in environmental and rescue work, it is conceivable that astronomy might comprise a small segment in the proposed program. Therefore, a follow-on program might be expanded to concentrate solely on infrared astronomy, complete with the folklore surrounding the early days of airborne research from a Lear jet. Either of these potential projects would be suitable for collaborative development between the SIRTF and SOFIA teams.

4.2.2 WIRE

The *Wide-Field InfraRed Explorer* (WIRE) is a NASA Small Explorer mission scheduled for launch in late 1998. Its scientific motivation is the study of starburst galaxies and their evolution in time. The Principal Investigator for WIRE is an adjunct staff member at IPAC, and WIRE Science Team co-investigators include the SIRTF Project Scientist, the Director of the SIRTF Science Center, and one of the SIRTF instrument Principal Investigators. Moreover, WIRE will fly mid-infrared detectors that are virtually identical with those being developed for use on SIRTF, thereby providing incalculable benefits to the ground system operations development for SIRTF. Finally, the centralized pipeline data processing of WIRE data will take place at IPAC, site of the SSC.

In other words, there is a powerful synergism between WIRE and SIRTF. Since WIRE is a SMEX mission and was selected prior to NASA's formalizing of EPO goals in space science, it cannot be expected to devote many of its modest and committed resources towards those educational goals. However, the technology and data processing links between WIRE and SIRTF fold neatly into the latter's EPO themes. The certainty that SIRTF will conduct follow-on investigations of targets initially studied by WIRE introduces yet another compelling reason for the SIRTF EPO team to develop a set of modules pertinent to the "scientific process" (see Section 3.5). Discussions between the SIRTF and WIRE teams have already taken place, and tentative EPO plans are being formulated along these lines.

4.2.3 2MASS

Another example of a modest-sized, but scientifically compelling, program is the *Two-Micron All-Sky Survey* (2MASS), a collaborative effort between the University of Massachusetts and JPL/IPAC. This ground-based, all-sky, near-infrared survey is an analog to the optical *Palomar Observatory Sky Survey* conducted in the 1950s (and being repeated with greater sensitivity and digital image processing in the 1990s). Northern Hemisphere survey operations began in 1997, and the Southern Hemisphere survey started in 1998. The 2MASS data, equivalent in volume to an IRAS mission every four nights, are being processed at IPAC. The three-color 2MASS survey, with simultaneous observations conducted at J, H, and K-bands (~1.25, 1.65, and 2.2 microns) will scientifically complement the 3.5-8.5 micron coverage afforded by SIRTF's IRAC camera. The 2MASS algorithms developed for accurate astrometry and photometry are of interest to SIRTF investigators, and demonstrate how future programs can rely on the heritage of earlier efforts to maximize the scientific utility, while minimizing costs. In addition, the SIRTF "freeze-frame" scanning technique at wavelengths longer than 24 microns is the same technique employed by 2MASS at short wavelengths. These stories will appear as part of SIRTF's EPO examination of the scientific process.

On a scientific level, the combination of 2MASS and SIRTF will also offer an important EPO opportunity. While 2MASS will likely catalog 100 million stars in our Galaxy and some one million galaxies in the Local Universe (all of which become potential targets for SIRTF), the exciting angle will follow from 2MASS's likely discovery of thousands of unusually very red infrared sources. Some of these peculiar objects may be dust-enshrouded quasars, and others may well be examples of the elusive brown dwarfs. Either way, SIRTF's timing and capabilities will provide the ability to pursue investigations of these "odd" sources, while providing the potential for discovering and characterizing completely new astronomical phenomena.

4.3 Integration with SIRTF Instrument Teams and Industrial Partners

The Pasadena-based SIRTF team will be exploring EPO opportunities with our partners around the country, including the three instrument teams and the two primary industrial partners.

The three SIRTF instruments, and their Principal Investigators, are:

- IRAC: InfraRed Array Camera, Giovanni Fazio (SAO)
- IRS: InfraRed Spectrograph, James Houck (Cornell U.)
- MIPS: Multi-band Imaging Photometer for SIRTF, George Rieke (U. of Arizona)

Members of these teams, or their associates, have expressed interest in the Project’s EPO activities. The SIRTF EPO Office will continue discussions on ensuring a efficient and collaborative development of material. Since the SIRTF instrument teams will be on a very fast-track development program to deliver their instruments within two years, any substantive EPO programs involving them are likely to focus on SIRTF’s operations phase.

The major industrial partners for SIRTF are Ball Aerospace and Technologies Corporation (Boulder, CO) and Lockheed-Martin Misssiles and Space (Sunnyvale, CA). The former is responsible for building the cryogenic telescope assembly, and the latter for the spacecraft. Their development of the SIRTF Observatory offers the potential for including topics that are relevant to the themes in Section 3.5. The SIRTF EPO team will soon be establishing contact with these industrial partners to explore interesting education and outreach opportunities. In addition, other contractors participate in the SIRTF development program, and they will be invited to join the SIRTF EPO program. At least one company has already established an EPO product; the Santa Barbara Research Center, provider of infrared detectors for SIRTF, has posted a tutorial on IR radiation and detectors on the Internet.

4.4 Integration with Other JPL Programs

As NASA’s premier center for planetary investigations, JPL offers many potential opportunities for collaborative development between SIRTF EPO and other programs. One example is the Planetary Data System (PDS) managed by JPL. It is a highly distributed system supporting archival storage of planetary data, along with the development of tools and techniques for scientific and public access to that data. The central node at JPL develops standards for archival storage media and data formats, and tools for query/retrieval/display/manipulation of archival mission data. Individual discipline nodes, located at a variety of universities and government agency sites, act as the curators for specific sets of mission data.

The imaging node of the PDS, managed by the U.S. Geological Survey in Flagstaff (with a sub-node at JPL), has developed a WWW-based set of tools for query and retrieval of imaging data from NASA/OSS planetary spacecraft. These Web-based tools include the *Planetary Photojournal,* a tool that enables the general public to access interesting imagery from past planetary science missions. The *Photojournal* is also used to disseminate the most recent press releases from current missions (e.g., *Mars Pathfinder*, *Galileo*, *Mars Global Surveyor*) during active flight operations. The *Photojournal* is currently experiencing approximately 500,000 accesses ("hits") per month.

An analogous system (a *Universe Photojournal*, perhaps?) , but adapted to the needs of SIRTF's outreach program, can be employed to provide public Web-based access to data released during flight operations. This will be a critical element of SIRTF's Legacy Science projects. These large community-led and peer-reviewed observing programs will consume much of SIRTF's first year of operations, and there will be no proprietary rights assigned to these data. The rapid release of Legacy Science data will permit the broad community -- scientist and the public alike -- an early look at SIRTF's results, and will permit archival research by astronomers within a year of launch.

NASA/OSS has also supported the development and operations of the Solar System Visualization Project at JPL for many years. This project is involved in the production of scientific visualization products for many different NASA programs. In recent years, the project has produced planetary fly-over animations from missions to Mars, animations illustrating the *Galileo* fly-bys of Earth and animations of solid models of asteroids derived from radar observations. Recently, funding from this task was combined with funding from other projects (including programs funded by the Telemetry and Mission Operations Directorate at JPL) to design and implement the first High Definition Television production capability within NASA, including the capability of displaying stereo imagery for viewing in 3-D. This technology was used to display and manipulate image mosaics of *Mars Pathfinder* data during the flight operations and science analysis phases. This technology is clearly adaptable to meet some of SIRTF's EPO objectives.

In a different realm, IPAC has long been the home for the NASA/IPAC Extragalactic Database (NED). This well-established and widely utilized electronic database of extragalactic objects serves as a super-catalog of data from worldwide literature. Its graphical user interface (now available via the WWW at *http://nedwww.ipac.caltech.edu/)* allows scientists, university and high-school students, and amateur astronomers alike to manipulate data to produce maps and a host of other products, including spectral energy distributions. Its powerful user-selected capabilities are ideal for performing multi-wavelength analysis of sources, complementing the themes and EPO modules introduced earlier.

The SIRTF Science Center will be an integral part of IPAC, thus reaping the synergistic benefits of existing products and tools. The SIRTF EPO program will build upon the education and public outreach efforts already started at IPAC (for example, visit the following Internet/WWW site **Error! Reference source not found.**.

Our EPO program has already forged an alliance with the international acclaimed and award-winning Telescopes in Education (TiE) program, based at JPL. This program provides access to a remote-controlled 24-inch diameter telescope atop nearby Mount Wilson to over 300 schools around the world. Students are able to program observing sequences and record images with an optical CCD camera. The SIRTF Project has arranged for an engineering-grade infrared array to be incorporated into the camera. With development of a suitable cryostat, the TiE program will be able to collect and analyze optical and near-infrared images. The SIRTF EPO team will also work with the staff at IPAC to incorporate the new 2MASS data archive into the TiE program as a complementary dataset to the individual TiE images and to the Palomar optical all-sky survey data.

With respect to education, JPL has established a suite of programs into which SIRTF EPO can seek leverage and opportunities. A multi-disciplinary Education Outreach Advisory Team has been organized at JPL, representing a cross-section of the Laboratory's projects and organizations. This Team is intended to be an active resource and development group that provides primarily a mentor role for JPL-wide EPO working groups. The SIRTF team will continue to interact with the JPL group in hopes of fostering an exchange ideas and experiences with the EPO representatives from the many planetary missions, Earth sciences programs, and technology demonstration experiments based at JPL. The wide diversity of these programs is expected to lead to multiple opportunities for collaborative development.

The SIRTF EPO efforts will also be coordinated and implemented in concert with the functions of JPL's Educational Affairs Office. This Office has already demonstrated competency in coordinating the formation of strategic education partnerships, and as a general resource for education information. This collective knowledge will be essential in assisting the SIRTF team in creating alliances where products and services developed in our EPO modules can be locally evaluated before any national distribution.

4.5 Integration with the Local Community

The opportunities for the creation, testing and assessment of EPO material, and of simply presenting astronomy lectures, are almost limitless in southern California. In addition to the California Institute of Technology, there is a significant infrared astronomy group at the University of California – Los Angeles (UCLA). Astronomers there have been instrumental in developing and testing infrared detectors, in building science instruments that incorporate these detectors, and in utilizing them in ground, airborne, and space applications. Moreover, the SOFIA Chief Scientist is based at UCLA.

The California State University system is the primary training ground for pre-college teachers in the state. As such, it represents a reservoir of science education talent that can be mobilized to participate in the SIRTF EPO endeavors. We intend to establish a teacher mentoring program, whereby newly-minted science teachers can attend summer Workshops to learn about infrared astronomy, to provide guidance and assistance in developing some of the SIRTF EPO modules under consideration, and to serve as field testing centers in their local schools. This will not only engage educators in the promotion of the national science/math/technology content standards, but will play a crucial role in supporting the NSES Professional Development Standards. Members of the Cal State – Los Angeles faculty have long participated in the collaborative development of material for JPL planetary missions, and have expressed interest in working with the SIRTF team. The large Cal State campus in Northridge is also a fertile source of candidate mentors.

The largest community college system in the nation is also in California, and JPL has recently created the JPL Undergraduate Scholars (JPLUS) program to recognize and encourage scholarly achievement among engineering, mathematics, computer science, and physical sciences students in the two-year colleges. JPLUS scholars are selected by community-college faculty and have the opportunity to compete for a Caltech/JPL Summer Undergraduate Research Fellowship (SURF). The SIRTF EPO team intends to work with the JPL Educational Affairs Office to select a handful of talented students to assist in the teacher Workshops. Their participation in the development and evaluation of materials will likely be very cost-effective, especially in the realm of Web design and content.

We also note that the largest community college in the state, with over 25,000 students, is the nearby Pasadena City College (PCC). A significant fraction of the PCC student population is comprised of groups that have typically been under-represented in the sciences, hence creating a natural opportunity for SIRTF EPO to establish a meaningful bridge to these communities.

At a more elementary level, the JPL Educational Affairs Office has linked up with the Indian Hills Education Village in Pomona. The centerpiece of this experimental program is a demonstration school and laboratory housed within a commercial shopping mall! In exchange of reduced rental fees, the commercial entities provide monetary and volunteer resources in support of the school's activities. Moreover, JPL scientists work with the school's teachers and with the area's community-college science teachers in a mentor role and in collaboratively developing science education modules suitable for the elementary school. We will take advantage of this relationship to test some of our K-6 material before widespread distribution.

The Los Angeles area also offers a rich variety of informal education centers. Two of them – one old and one new – are of particular interest to SIRTF. The historic Griffith Park Observatory in Los Angeles offers monthly astronomy lectures and public observing sessions. We will actively engage the Griffith staff and audiences to participate in our EPO program, and to assist in the evaluation of modules.

The new California Science Center, near the Los Angeles Memorial Coliseum and the University of Southern California, opened in February 1998. It is the culmination of a $130-million conversion of the old Museum of Science and Industry into a wondrous destination where children and adults alike can learn about themselves and the world around them. A future $65-million exhibit hall, "Worlds Beyond," will be devoted to astronomy and space exploration. Our team eagerly anticipates visiting the Center and seeking ways in which SIRTF EPO can contribute to this new civic treasure.

By 2001, the year of SIRTF's launch, a neighborhood elementary school will be located on the Science Center campus. The magnet school for mathematics and science will have 700 students and be affiliated with the USC School of Education, and will be part of the Los Angeles Unified School District. The school will include a Science Education Resource Center, funded in part by JPL and local aerospace corporations, and will serve as a development center for educators, parents, and community groups. The SIRTF EPO hopes to build a solid working relationship with the California Science Center, and to help develop materials that can be an important part of their new endeavor.

4.6 Integration with NASA Education

NASA's education vision is to "promote excellence in America's education system by providing access and engagement in NASA's exciting missions." This vision is a direct result of the Congressional language creating NASA itself in 1958. This vision is implemented through JPL and the nine NASA Field Centers, and is targeted at elementary, secondary, undergraduate, graduate, and postdoctoral levels. The science, mathematics, and technology education programs and activities leverage NASA's inspiration, its unique facilities, and its specialized workforce in pursuit of its education and outreach goals.

To that end, NASA formulated a Strategic Plan for Education in 1992 to establish a general direction and guidance for the implementation and management of NASA's education programs. The document contains five categories of Program Objectives, which are summarized below. Some of the ways in which the SIRTF EPO Plan are relevant to these objectives are also noted.

- Teacher/Faculty Preparation and Enhancement Programs

  These programs are designed to provide opportunities for teachers and faculty to enhance knowledge and teaching skills through the use of NASA-related topics and research. Many of the SIRTF EPO modules, particularly those introduced throughout Section 3.5 ("The Scientific Process"), will clearly support these programs.

- Curriculum Support and Dissemination Programs

  The intent here is to provide instructional materials based on NASA's unique mission and resources in the areas of science, engineering, technology, and mathematics, thereby leading to an increase in student interest, involvement, and achievement. All of SIRTF's EPO modules will be designed to be a potential element in school curriculum. The initial focus on the elementary education and middle-school levels will be on Modules 1 and 2, which are already under development. Modules 3-5, part of the theme "From Photons to Knowledge," can safely be directed towards secondary education levels. Some of the "Scientific Process" modules will target secondary schools; all of them will be an integral part of the teacher mentoring program we intend to establish and sustain.

- Support for Systemic Change

  This objective encourages organizational reform and systemic (permanent) change through individual and collaborative efforts with a range of partnerships. To the extent that SIRTF's EPO Plan is guided by the various national education standards mentioned earlier, we are certain that the developed Modules will encourage a query-based and "hands-on" experience, consistent with the calls for reform. Particular manifestations of these reforms to which SIRTF might well interface are the NASA Space Grant Colleges and the Aerospace Education Services Program (AESP). Many of the EPO modules would likely contribute to the professional development of specialists in the AESP, and SIRTF would likely benefit from considerable leveraging opportunities in the dissemination of our education programs and activities.

- Student Support Programs

  These programs are intended to offer enrichment experiences and financial support for science, engineering, technology, and mathematics students in research or industrial settings, and thereby foster careers in those fields. The implementation of SIRTF's EPO Plan will provide student intern opportunities, for which selected students from local industrial firms -- perhaps those directly supporting the SIRTF development effort – might visit JPL and the SSC. The intention would be for them to participate in EPO workshops and in the actual development of certain modules, particularly those emphasizing the technologies that enable SIRTF's scientific capabilities. We will consult with JPL's education specialists to ascertain the viability of this program at the local level.

- Educational Technology Programs

  These programs encourage the use of advanced technologies for education, including Internet services, CR-ROM databases, live or taped video, computer software, multimedia systems, and virtual reality. While the actual choice of dissemination materials for SIRTF modules and products will be made later, it is easy to anticipate that the choices will likely utilize all of these technologies – and more.

4.7 Integration with JPL/NASA Public Affairs

The *public outreach* efforts described in this Plan are intended to target specific audiences and constituencies. *Public affairs* activities, on the other hand, concentrate primarily on working with the mass media to widely communicate the newsworthy NASA stories. The SIRTF Project Office and JPL Public Affairs Office are developing a separate SIRTF Public Affairs Plan. This companion document will describe news media activities and public affairs products through all mission phases -- from planning, design, development, and pre-launch preparations to the actual launch, and subsequent operations through the end of the mission.

The SIRTF EPO activities and schedules will clearly be integrated with those pertaining to public affairs. We will work closely with staff at both the JPL Public Affairs Office, the NASA Origins Program Office at JPL, and with the cognizant officers within the Office of Space Science at NASA Headquarters to ensure a seamless integration of efforts and a synergistic public impact. For example, a potential Discovery channel television documentary on infrared astronomy (see Section 4.2.1) might be produced such that it would broadcast shortly before the SIRTF and SOFIA programs become operational in late 2001. Such a broadcast on the second-most distributed cable television network would complement the NASA public affairs coverage supporting the deployment of SOFIA and the launch of SIRTF.

The SIRTF EPO team is likely to contribute to many NASA and JPL public affairs activities and products, including video animations, photographic prints/negatives/slides, press kits, mission fact sheets, news releases, and mission status reports. Many of these products will also be available online through the SIRTF Web site (see Section 5).

5. "SIRTF"ing the Internet

The explosive growth of the Internet and its graphical World-Wide Web (WWW) is a phenomenon that might properly be assessed only as a historical study. A recent Public Broadcasting Service television series, "*A Science Odyssey*," may have established a comprehensible context. The program alleged that the wide utility of many inventions, and their ultimate societal ramifications, were usually undreamed of at birth (e.g., automobiles, airplanes, radio, polymers, transistors, computers), and could only be appreciated in hindsight. However, as the TV program alluded, many of us who rely on the Web have this feeling that we are participating in an historic development -- as it is occurring.

Over one-third of American homes now have at least one personal computer. The advent of the sub-thousand dollar PC makes it likely that most US homes will soon have a computer. The introduction of Web-TVs and the proliferation of interesting, fun and (occasionally educational) WWW sites will afford even greater Internet penetration, especially at home. The number of Internet users is doubling every year. If the trends of 1989 to the present continue, there will be 400 million Internet hosts and one billion users by the time SIRTF launches!

JPL-based Web sites are among those with the heaviest access, especially during times of newsworthy planetary encounters. Among sites with peak access of over one million "hits" daily were the Comet Shoemaker-Levy 9 impact of Jupiter in 1994, the Galileo probe's Jovian encounter in 1995, and the passage of Comet Hale-Bopp in March 1997. But these amazing stories were eclipsed in Web history on July 8, 1997 when the news of *Mars Pathfinder* and its *Sojourner* exploratory rover led to an astounding 47 million hits on that one day alone (alleged to be a world record). *Pathfinder/Sojourner* redefined the manner in which future space science missions will utilize the Web to enable the general public to experience the same awe and thrills that the participating scientists get to experience.

Will SIRTF stir that kind of interest? Perhaps not; but then who knows what SIRTF may discover? The anticipated results from SIRTF have the potential to rival the popular HST results that are widely disseminated via the STScI Web site and the NASA Agency site. SIRTF will almost certainly follow the example of HST and make Early Release Observations available for general release, partly to demonstrate the Observatory's capability, but also to let the general public and the media share the excitement of seeing what a quarter-century of hard work was all about!

To efficiently exploit its "orders of magnitude" increase in capability, SIRTF has defined an innovative observing opportunity -- the Legacy Science Program. Roughly half a dozen community-led investigations, selected by peer review, will be scheduled and implemented during SIRTF's first year of science operations. Legacy Science projects will be large and scientifically coherent investigations, likely to include many hundreds of hours of observing time each. Since Legacy Science projects carry no proprietary rights, the data will become available to the entire scientific community and to the general public as soon as it is calibrated and validated ("SIRTF-ied"). The SSC intends to design systems that permit Internet access to the data, and various software tools to permit manipulation and analysis of the data, thereby promoting early archival research.

Hence the Web will not only be of interest to the media and public, but will be an important tool for the SIRTF user community, too. The SIRTF Science Center intends for the Web to be the primary means by which the scientific community will "visit" the SSC. It is the intention of the SSC to develop online software tools for planning observational programs, for distributing the Calls for Proposals, for answering questions, and for accepting scientific observing proposals from the community. Once approved programs are scheduled, interested users will be able to track the status of the their observations on the Web.

As SIRTF begins formal development in April 1998, a newly redesigned and enhanced SIRTF Web site is about to make its debut, and will be "housed" at the SSC (*http://ssc.ipac.caltech.edu/sirtf*). The new architecture seeks to anticipate the future needs of all segments of the SIRTF community, including the science community, the public and media, teachers and students. The new site will naturally contain links to related programmatic, scientific, and educational sites, and to valuable electronic warehouses of space science information and materials (e.g., NASA Spacelink, NASA Education Resource Centers). The new organizational structure of the SSC/SIRTF Web site is summarized in Appendix G.

The potential power of the WWW is just beginning to be appreciated and utilized. In recent years, Web-based tools supporting "immersive" data display and three-dimensional data manipulation have been developed and are now available to the general public. These tools will continue to evolve in the next several years, and can be exploited to support the educational objectives outlined in this Plan by providing the capability of interactively roaming through science data sets released by SIRTF to illustrate key educational concepts.

One effective tool that is already available is the Virtual Reality Modeling Language (VRML). VRML was originally designed as a language to enable efficient implementation of video games. The engineering and scientific community has utilized VRML to permit scientists to interactively roam and travel through multidimensional data sets. As an example, VRML was used to support a public Web site providing the capability for a home PC user to interactively fly over a three-dimensional perspective view of the Martian terrain surrounding the *Mars Pathfinder* landing site. This VRML Web page became the most frequently accessed VRML site in Web history. VRML, and its successors, can be used effectively to illustrate the scientific themes embodied within the SIRTF EPO Plan by enabling immersive user navigation of visualization products developed using data from SIRTF.

6. Measures of Success

The NASA/OSS Implementation Principles for Education and Public Outreach (Appendix B) require that activities, programs, and products must be evaluated for quality, impact, and effectiveness. To that end, we will establish the formal mechanisms necessary for the measurement and evaluation of all SIRTF EPO efforts, and make the data available to NASA Headquarters, and other interested parties. The SIRTF team will consult with members of NASA's Office of Space Science and with the Education Division of the Office of Human Resources and Education to define the appropriate metrics that will be most useful for evaluation purposes. It is anticipated that the JPL Educational Affairs Office and the cross-disciplinary JPL Education Outreach Advisory Team can also provide useful metrics for assessing the effectiveness of the SIRTF EPO programs.

We will rely on both internal self-evaluation and reviews by external bodies to judge the efficacy of the SIRTF EPO efforts, and to offer suggestions for improvement, where necessary. Within the next year, we anticipate organizing and chartering the SIRTF/IPAC EPO Advisory Group to provide continuing assessment of our efforts and an experienced objective review of our module development plans and implementation strategies. While candidates for membership have been identified, they have not yet been contacted, and it is therefore premature to list members in this Plan.

A summary of the candidate EPO modules, some already under development, is listed below. The numbers in angular brackets refer to the Section of this Plan where the module was first introduced.

Theme: The Concept of Temperature

(1) The Nature of Light {3.3.1}
(2) More Than the Eye Can See: Infrared Radiation {3.3.2}

<u>Theme: From Photons to Knowledge</u>
(3) Decoding Radiation {3.4.1}
(4) Critical Thinking {3.4.1}
(5) Visualizing Data {3.4.2}

<u>Theme: The Scientific Process</u>
(6) Posing the Key Questions {3.5.1}
(7) Capturing Photons {3.5.2}
(8) Better Science Through Engineering {3.5.2}
(9) Build a Space Observatory {3.5.2}
(10) Choosing an Astro-Tool {3.5.3}
(11) Stunning Images, Revealing Spectra {3.5.4}
(12) Our Knowledge Evolves {3.5.5}
(13) Lifting the Science Veil {3.5.6}

An important means of evaluating the potential impact and relevancy of SIRTF's proposed EPO Plan is to examine and ensure its consistency with the National Science Education Standards, the NCTM Mathematics Standards, and the proposed ITEA Technology Education Standards. To gauge the potential relevance of the science content inherent in the SIRTF modules, we cross-reference the modules to the standards listed in Table 1. Note that there can be no singular mapping into the standards; much will depend on the specific content that ends up being included in the SIRTF modules. Nevertheless, a significant overlap suggests that the proposed EPO Plan holds substantial promise in contributing to the nation's educational reform efforts. The final verdict, of course, must await the implementation of this Plan's contents and a careful and proper assessment by trained evaluators. To the extent that we actively pursue teacher mentor programs and engage them in our efforts, especially with regard to Modules 6-13, the groundwork is also in place for a solid contribution to the NSES Professional Development Standards.

The broad NCTM Mathematics Standards listed in Table 2 contain many more detailed and substantive goals that are beyond the scope of this document to enumerate. We note, however, that the students' examination and selection of suitable orbits in Module 9 is directly relevant to material contained in *"Mission Mathematics: Linking Aerospace and the NCTM Standards,"* a joint NASA/NCTM publication. Another link to this applied curriculum development is the means by which ground-based astronomers communicate with orbiting spacecraft, another likely component of Module 9.

As reported earlier, the dramatic technologies that enable SIRTF to be a true "Great Observatory" are an obvious and natural link to the proposed ITEA technology education standards. The EPO modules summarized above are rich in technological content and offer wonderful opportunities to implement the technology standards. Modules 2, 7, 8, 9, 10 and 13 are so inherently relevant to the ITEA standards that we refrain from adding cross-referencing clutter to Table 3. Suffice it to say that the modules introduced as part of the "scientific process" theme are likely to be closely aligned with the standards, especially with the first four technology dimensions contained in the table.

In summary, the SIRTF EPO Plan has introduced some of the thematic modules we envision developing. This Plan is not intended to be an exhaustive accounting of planned activities, but rather serves as a vision of where we feel SIRTF can make a significant impact on the current body of space science education and public outreach material.

A critical component of the Plan will be the objective and expert evaluation of our programs. We will rely on an Advisory Group to provide useful guidance and a measure of assessment throughout the course of our efforts. It is anticipated that the SIRTF EPO activities will also be reviewed periodically by the SIRTF Science Working Group, particularly by its Outreach Coordinator, Dr. Marcia Rieke. Additional oversight will be provided by the soon-to-be-chartered SIRTF Users Group and by the IPAC Users Committee. We also will define a more rigorous set of evaluation metrics, following consultations with assessment experts within JPL, NASA, and the external community.

Whatever formal mechanisms are established to assess SIRTF's education and public outreach program, we remain confident that the ultimate measure of success will be the degree to which teachers, students, and other members of the general public come back to us -- and ask for more!

Table 1
NSES Science Content Standards

Grades K-4	Grades 5-8	Grades 9-12
Science as Inquiry		
• Abilities necessary to do scientific inquiry (4,5,6,10) • Understanding about scientific inquiry (1,2,3,8,12,13)	• Abilities necessary to do scientific inquiry (4,5,6,10) • Understanding about scientific inquiry (1,2,3,8,12,13)	• Abilities necessary to do scientific inquiry (4,5,6,10) • Understanding about scientific inquiry (1,2,3,8,12,13)
Physical Science		
• Properties of objects & materials (2)	• Properties & changes of properties in matter (2,3,11)	• Structure of atoms (1,2)
• Position & motion of objects (9)	• Motions & forces (9)	• Structure & properties of matter (2,11)
• Light, heat, electricity & magnetism (1,2,3)	• Transfer of energy (2,3,7)	• Chemical reactions (2,7,11)
		• Motions & forces (9) • Conservation of energy & increase in disorder • Interactions of energy & matter (7,11)
Earth and Space Science		
• Properties of earth materials	• Structure of the earth system	• Energy in the earth system (2)
• Objects in the sky (1,2,3,9)	• Earth's history	• Geochemical cycles
• Changes in earth & sky (2,3)	• Earth in the solar system (9)	• Origin & evolution of the earth system (6) • Origin & evolution of the universe (6)
Science and Technology		
• Abilities to distinguish between natural objects & objects made by humans (4)	• Abilities of technological design (8,9)	• Abilities of technological design (8,9)
• Abilities of technological design (8,9)	• Understanding about science & technology (8,9,10)	• Understanding about science & technology (8,9,10)
• Understanding about science & technology (8,9,10)		
Science in Personal and Social Perspectives		
• Personal health	• Personal health	• Personal & community health
• Characteristics & changes in populations	• Populations, resources & environments	• Population growth
• Types of resources	• Natural hazards (9)	• Natural resources
• Changes in environments	• Risks & benefits (8,9)	• Environmental quality
• Science & technology in local challenges	• Science & technology in society (8,13)	• Natural & human-induced hazards
		• Science & technology in local, national & global challenges (8,13)
History and Nature of Science		
• Science as a human endeavor (12,13)	• Science as a human endeavor (12,13)	• Science as a human endeavor (12,13)
	• Nature of science (6,10,12,13)	• Nature of scientific knowledge (6,10,12,13)
	• History of science	• Historical perspectives

Table 2
NCTM Mathematical Curriculum Standards

	Grades K-4	Grades 5-8	Grades 9-12
1	Mathematics as Problem Solving	Mathematics as Problem Solving	Mathematics as Problem Solving
2	Mathematics as Communication	Mathematics as Communication	Mathematics as Communication
3	Mathematics as Reasoning	Mathematics as Reasoning	Mathematics as Reasoning
4	Mathematical Connections	Mathematical Connections	Mathematical Connections
5	Estimation	Number and Number Relationships	Algebra
6	Number Sense and Numeration	Number Systems and Number Theory	Functions
7	Concepts of Whole Number Operations	Computation and Estimation	Geometry from a Synthetic Perspective
8	Whole Number Computation	Patterns and Functions	Geometry from an Algebraic Perspective
9	Geometry and Spatial Sense	Algebra	Trigonometry
10	Measurement	Statistics	Statistics
11	Statistics and Probability	Probability	Probability
12	Fractions and Decimals	Geometry	Discrete Mathematics
13	Patterns and Relationships	Measurement	Conceptual Underpinnings of Calculus
14			Mathematical Structure

Appendix A:
The NASA/OSS Education and Public Outreach Strategies

The NASA/OSS EPO Strategies listed in the 1995 document, *"Partners in Education: A Strategy for Integrating Education and Public Outreach into NASA's Space Science Programs,"* are summarized below.

(1) Focus on what educators need.

(2) Focus on the unique contributions OSS can make to education and to enhancing scientific and technological literacy.

(3) Forge long-term partnerships with education institutions and professionals.

(4) Encourage a wide range of educational and public outreach activities.

(5) Foster full participation of groups currently under-represented in the space sciences.

(6) Incorporate the latest information dissemination and display technologies into education and public outreach programs.

Appendix B: The NASA/OSS Education and Public Outreach Implementation Principles

The 1996 document, "*Implementing the Office of Space Science (OSS) Education/Public Outreach Strategy,*" introduces the following principles for OSS management and the OSS research community in implementing its EPO strategies.

¶ Involve scientists in education and outreach in ways that enhance core OSS goals

¶ Make a long-term sustained commitment to integrating education and outreach into OSS missions and outreach programs by:
- Validating education/outreach as a priority for OSS
- Providing resources
- Building education and outreach into all aspects of the OSS program
- Aligning implementation along OSS themes
- Recognizing and rewarding contributions to education and outreach
- Integrating science and education at the NASA Centers

¶ Support local, state, and national efforts directed towards systemic reform of science, mathematics, and technology education

¶ Base OSS-developed educational products and activities on the criteria contained in the national Mathematics, Science, and Technology Education Standards

¶ Help scientists become involved in education/outreach by:
- Creating a network of brokers/facilitators
- Providing opportunities for appropriate training
- Removing contractual and other impediments to participation

¶ Provide meaningful opportunities for under-served and underutilized groups

¶ Enhance the breadth and effectiveness of partnerships among scientists, educators, contractors, and professional organizations as the basis for OSS education and outreach activities by:
- Focusing on high leverage opportunities
- Building on existing programs, institutions, and infrastructure
- Emphasizing collaborations with planetariums and science museums
- Coordinating with other ongoing education and outreach efforts, both inside NASA, and within other Government agencies
- Involving the contractors in OSS's education/outreach programs

¶ Make materials widely available and easily accessible, using modern information and communication technologies, where appropriate

¶ Evaluate for quality, impact, and effectiveness

Appendix C: Acronyms

2MASS	Two-Micron All-Sky Survey
AAS	American Astronomical Society
ASP	Astronomical Society of the Pacific
AXAF	Advanced X-Ray Astrophysics Facility
CGRO	Compton Gamma-Ray Observatory
EPO	Education and Public Outreach
FOSTER	Flight Opportunities for Science Teacher EnRichment
GSFC	Goddard Space Flight Center
HST	Hubble Space Telescope
IDEA	Initiative to Develop Education through Astronomy
ITEA	International Technology Education Association
IPAC	Infrared Processing and Analysis Center
IRAC	InfraRed Array Camera
IRAS	InfraRed Astronomical Satellite
IRS	InfraRed Spectrograph
ISO	Infrared Space Observatory
JPL	Jet Propulsion Laboratory
JPLUS	JPL Undergraduate Scholars
KAO	Kuiper Airborne Observatory
MIPS	Multi-band Imaging Photometer for SIRTF
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NCTM	National Council of Teachers of Mathematics
NED	NASA/IPAC Extragalactic Database
NGST	Next Generation Space Telescope
NICMOS	Near-Infrared Camera and Multi-Object Spectrometer
NSES	National Science Education Standards
OSS	Office of Space Science
PDS	Planetary Data System
SAO	Smithsonian Astrophysical Observatory
SCS	Science Content Standards
SEC	Sun - Earth Connection
SEU	Structure and Evolution of the Universe
SIM	Space Interferometry Mission
SIRTF	Space InfraRed Telescope Facility
SOFIA	Stratospheric Observatory For Infrared Astronomy
SolSysEx	Solar System Exploration
SSC	SIRTF Science Center
STScI	Space Telescope Science Institute
SURF	Summer Undergraduate Research Fellows
SWG	Science Working Group
TiE	Telescopes in Education
TPF	Terrestrial Planet Finder
ULIRG	Ultra-Luminous InfraRed Galaxy
VRML	Virtual Reality Modeling Language
WIRE	Wide-Field Infrared Explorer
WWW	World-Wide Web
XMM	X-ray Multi-mirror Mission
XTE	X-ray Timing Explorer

Appendix D: Biographies of Key Personnel

Dr. Michael D. Bicay earned B.S. degrees in Physics and Mathematics at the University of Wisconsin - Eau Claire in 1981. His M.S. (1983) and Ph.D. (1987) degrees in Applied Physics were conferred by Stanford University. The research for his Ph.D. dissertation was carried out during a three-year residency at the National Astronomy and Ionosphere Center's Arecibo Observatory in Puerto Rico. Upon returning to the mainland US, he accepted a National Research Council fellowship at Caltech/IPAC. In 1989, he transferred to a position on the staff at IPAC. One year later, he accepted a visiting scientist appointment in the Astrophysics Division of OSS at NASA Headquarters, where he spent the next six years as Program Scientist for various infrared, submillimeter and radio missions and programs. After returning to Pasadena in 1996, he joined the science staff of JPL's Space and Earth Sciences Directorate, and was a member of the science staff in the SIRTF Project Office. Dr. Bicay recently transferred to Caltech, where he will serve as Manager of the Science, Education and Outreach programs at IPAC.

While in Washington, he became involved in various education and public outreach activities, and served as a consultant to the Smithsonian National Air and Space Museum (NASM). Among the products/activities that he played a major design and/or development role are:

- *"Perspectives From Space,"* a series of eight educational posters produced by various NASA science Offices to commemorate International Space Year in 1992;

- *"Portrait of the Milky Way,"* educational booklet to accompany the poster/painting that celebrated the ongoing <u>Where Next, Columbus?</u> exhibit at NASM;

- *"Viewing the Violent Universe: The Compton Gamma-Ray Observatory,"* an exhibit in the main lobby at NASM; and

- *"Braille Cosmology -- A Map of Our Evolving Universe,"* a tactile poster depicting the cosmological evolution of space and time, developed as a joint collaboration between NASA/OSS and the American Council for the Blind.

Dr. Marcia J. Rieke earned a B.S. degree in physics at the Massachusetts Institute of Technology in 1972 and a Ph.D. in physics from the same institution in 1976. After receiving her degree she accepted a post-doctoral position at the University of Arizona working on ground-based infrared astronomy. She has continued to work at Arizona where she is now a Professor of Astronomy. As part of her university duties, she has taught astronomy classes with the majority of her teaching conducted at the introductory level for non-science majors. In 1985 she began working on the project that led to the construction of the *Near-Infrared Camera and Multi-Object Spectrometer* (NICMOS), a project where she has served as Deputy Principal Investigator. She assumed the role of Outreach Coordinator for SIRTF in 1991. She recently received funding through the IDEA program to develop a classroom demonstration of a simple infrared detector.

Dr. Michelle L. Thaller earned a B.A. degree in astrophysics from Harvard University in 1992 and a Ph.D. from Georgia State University in 1998. Research for her dissertation was conducted at Kitt Peak National Observatory in Arizona, Mount Stromlo and Siding Springs Observatory in

Australia, and with NASA's *International Ultraviolet Explorer* and *Hubble Space Telescope*. She has been an award-winning graduate teaching assistant, and received the Outstanding Graduate Student prize for research and teaching in 1997. Throughout her gradate career, she led her department's outreach efforts, hosting numerous open houses and public evenings, and has appeared on local Atlanta television. Beginning as an undergraduate, Dr. Thaller has taught astronomy as part of the Johns Hopkins University's educational research office at the Center for Talented Youth, and was studied as an example of an effective science teacher. Dr. Thaller has recently joined the science staff of the SIRTF Science Center at IPAC.

Appendix E: Implementation Schedule

Detailed schedules of activities will be prepared on an annual basis for review, as necessary. For purposes of this Plan, we present a top-level schedule of anticipated activities currently envisioned. This is not intended to be an exhaustive list of SIRTF EPO activities.

FY 1998:

- Purchase a portable infrared camera for demonstrations. (completed)
- Develop several demonstrations using the infrared camera for both educational and public outreach. (partially completed)
- Enhance the EPO aspects of the SIRTF Web site. (in development)
- Participate in the National Science Teacher's Conference by demonstrating the electromagnetic spectrum through the use of the infrared camera. Distribute copies of the "Orion" lithograph. (in development)
- Support IDEA grant to develop a hands-on exercise illustrating several principals of electromagnetic radiation (in development)
- Develop working relationships with EPO partners such as the set of "Brokers", Forums, Challenger Centers, and museums and planetariums in SIRTF-related neighborhoods.
- Begin operation of SIRTF EPO office at the SIRTF Science Center.

FY 1999:

- Continued development of the educational and public outreach portions of the SIRTF Web site.
- Select high schools to participate in the "Observe with SIRTF" program.
- Begin development of a thermal physics module incorporating the hands-on exercises developed under the IDEA grant.
- Develop content of teacher workshops that will prepare teachers to use the SIRTF data in conjunction with curricula such as the thermal physics module.
- Increase participation at national science teacher conferences.
- Begin gathering of materials to be used in support of pre-launch publicity.
- Begin construction of an infrared camera to use on Gil Clark's Mt. Wilson telescope. Data samples will be used in conjunction with the electromagnetic spectrum theme and also related to NICMOS data from HST.

FY 2000:

- Completion and initial distribution of thermal physics module.
- Initiation of teacher workshops.
- Further work with groups of high school students participating in the "Observe with SIRTF" program.
- Continued development of the Web site.
- Increased work on publicity materials including production of slide sets and other aids for pre-launch talks.

FY 2001:

- Purchase more infrared cameras to be used in demonstrations at planetariums, etc.
- Produce more detailed and elaborate materials such as animations and videos to support pre-launch activities.
- Continuation of teacher workshops. Consider a program of having teachers attached to both SIRTF instrument teams as well as Legacy Project teams.
- Final preparations with high school students to take advantage of observing with SIRTF.
- Prepare to have Web site expand its public outreach capabilities.

FY 2002:

- More teacher workshops will be held with a transition to summer workshops.
- Expansion of Web presence to highlight recent results from SIRTF.
- Development of animations to support the first discoveries.
- Development and production of press kits and generally available pictures and posters displaying SIRTF science discoveries.
- Complete program with the high school students with the delivery of actual SIRTF data.

Future Years of Operation:

- Continued presentation and dissemination of SIRTF discoveries.
- Continuation of teacher workshops.
- Revision of existing educational materials and development of new materials.
- Continued enhancement of Web site.

Appendix F: Annual EPO Budgets

The SIRTF Project has allocated the following amounts ($K) for Education and Public Outreach activities. The total EPO level of funding is $9.555 million over a 9.5-year period. Note that FY1998 EPO activities commence at the start of Phase C/D in April 1998.

FY	Phase C/D	Phase E
1998	200	
1999	500	
2000	800	
2001	1000	
2002	500	875
2003		1300
2004		1300
2005		1300
2006		1300
2007		450
TOTAL	**3000**	**6525**

Appendix G: SIRTF Web Architecture

The SIRTF Internet/WWW site is being redesigned to meet the long-term needs of the scientific and educational communities, and of the general public and mass media. The new site should be deployed in the spring of 1998. The architecture for the redesigned site is presented below. Many of the EPO modules introduced in the Plan may be suitable for inclusion in the Education and Public Outreach section of the site.

¶ <u>About SIRTF</u>

- Overview of the Mission
- Mission Background
    - The Rationale for Infrared Astronomy
    - The Heritage of SIRTF
    - Dramatic Technology Developments
    - The “Decade of the Infrared”
    - A Revalidation of SIRTF
    - Seeking Efficiency, While Leaving a Legacy
- SIRTF Science Themes
    - Overview
    - Brown Dwarfs and Super-Planets
    - Protoplanetary and Planetary Debris Disks
    - Ultraluminous Galaxies and Active Galactic Nuclei
    - The Early Universe
    - Other Science Enabled by SIRTF
- The SIRTF Family
    - The “Great Observatories”
    - SOFIA
    - NASA’s Origins Program
- The SIRTF Design
    - Launch Vehicle and Orbit
    - Thermal and Cryogenic System
    - Optics and Telescope Assembly
    - Spacecraft Subsystems
    - Science Instruments

¶ <u>About the SSC</u>

- SSC Charter / Purpose
- Products and Services
- Organizational Structure
- Staff / Contact List
- Available Job Positions
- SIRTF Users Group

¶ Observing with SIRTF

- Community Participation
  - An Invitation to the Community
  - Types of SIRTF Observing Programs
- Science Instruments
  - IRAC
  - IRS
  - MIPS
- Proposal Planning and Preparation
  - Sky Visibility Charts
  - Time and Sensitivity Estimators
  - Performance Estimation Tool
  - Observatory Manual
  - Instrument Handbooks
  - Calls for Proposals (CPs)
- Schedules
  - Project Schedules
  - Science Activity Schedules
- Mission Status Reports
  - Instrument Performances
  - Calibration
  - Observations Logs
- Documents
  - Baseline Observatory Design (the "Green Book")
  - Science Requirements Document
  - Observatory Manual
  - Instrument Handbooks
  - White Papers
- Workshops and Reports
  - Legacy Science Conference III (2000)
  - Legacy Science Conference II (1999)
  - Legacy Science Conference I (1998)
  - "Astrophysics with Infrared Surveys: A Prelude to SIRTF"
  - American Astronomical Society Meetings
  - Other Science Conferences
- Advisory Groups
  - Science Working Group (SWG)
  - SIRTF Users Group (SUG)
  - Community Task Force (CTF)
  - SSC Oversight Committee (SSCOC)
  - IPAC Users Group
- Data Analysis
  - Data Analysis Awards
  - Archival Research Program
- Frequently Asked Questions (FAQs)
- Other Links

¶ Education and Public Outreach

- Infrared Astronomy
- Educators Forum
    - Lesson Plans
- Kids Zone
    - Stories and Quizzes
    - Infrared / Optical Games
    - Build Your Own SIRTF
- Ask an Astronomer
    - Indexed Q & A
- Links to Other Educational Sites

¶ <u>The Media Room</u>

- SIRTF News
    - "What's New?"
    - Previous News Releases
- Mass Media Articles
- Science Image Gallery
- The Image Warehouse
    - Indexed catalog of images and viewgraphs to support Speaker's Bureau